NAVY SCIENTIFIC PAPERS, No. 11

STEEL FOR SHIP BUILDING

NAVY SCIENTIFIC PAPERS, No. 11,

PAPERS AND DISCUSSIONS

ON

STEEL FOR SHIP-BUILDING.

REPRINTED FROM TRANSACTIONS

OF THE

INSTITUTION OF NAVAL ARCHITECTS.

BUREAU OF NAVIGATION,
NAVY DEPARTMENT.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
3559 1883.

CONTENTS.

	Page.
On Steel for Ship-building	5
On Steel in the Ship-building Yard	50
On Steel for Ship-building	73
On the increased use of Steel in Ship-building	101
On the use of Mild Steel for Ship-building in the Dockyards of the French Navy	118
The Almirante Brown, Argentine Cased Corvette	172
The Structural Arrangements and Proportions of H. M. S. Iris	134

ON STEEL FOR SHIP-BUILDING.

By B. MARTELL, Esq., *chief surveyor of Lloyd's Register of British and Foreign Shipping, Member of Council.*

[Read at the nineteenth session of the Institution of Naval Architects, April 11, 1878; the Right Hon. LORD HAMPTON, G. C. B., D. C. L., president, in the chair.]

The question of the use of steel for ship-building purposes has occupied considerable attention for many years by those interested in shipping, and one or more valuable papers bearing on this subject have been read at the meetings of this institution; but it is, perhaps, not too much to say that circumstances have now brought the question to the front in a more urgent and practical form than heretofore, and in my opinion it was never so ripe for discussion as at the present time; and just now the production of any experience which can throw light on its mechanical or commercial aspect will be of special value and significance.

The prominent position occupied by mild steel during the last year or two, and particularly very recently, has induced ship-owners as a body to look forward with the greatest interest to the probabilities of its becoming the material for ship-building in the immediate future, and they desire at the present moment to be informed of the advantages or otherwise which experience so far has already shown to arise from the use of this material for the construction of vessels for general mercantile purposes.

It has been long felt that the production of a material like the present mild steel, possessing its properties of ductility and superior strength, and being perfectly uniform and homogeneous in quality, would be a most desirable substitute for the ordinary iron used in the construction of our mercantile vessels. Till the last year or two much doubt existed whether these conditions could be insured to the required extent, and especially whether it could be produced at such a cost compared with iron as would enable ship-owners to recoup themselves for the additional outlay.

The time has now come when it is said by many others besides the manufacturers, that steel can be used with as much confidence as iron; and it is held that whilst the properties of mild steel are in every respect superior to iron, the cost—having regard to the reduced weight required—will warrant the ship-owner, from a commercial point of view, in adopting the lighter and stronger material.

These opinions are undoubtedly shared by many ship-owners, as would appear from the fact of steel vessels at the present time being in course of construction. I may mention that during the last twelve months the committee of Lloyd's Register of Shipping have had placed before them for their approval the particulars of over 5,000 tons of sailing ships and 18,000 tons of steamers, with a view, if built, to a class in the Register Book of their Society.

These facts all seem to indicate that steel ship-building on a large scale is becoming a reality, and this is why I think the present an opportune moment to raise the question before the members of this institution, as a discussion of it here cannot fail to afford valuable information to all who are interested in the subject.

The question appears to present itself for consideration under the two following heads:

First. The peculiar properties of mild steel for ship-building, as regards its comparative strength, uniformity, and rigidity; the changes observable under manipulation, the effects of riveting, and the general durability as compared with iron.

Secondly. The relative cost, and commercial advantages or otherwise to be derived from its use in the construction of sailing ships and steamers for various purposes of trade.

Until recently the experience of those who had used and observed the working of steel for ship-building was not so satisfactory as to justify them in recommending its general adoption for the construction of vessels of all sizes and for every purpose of trade. On the other hand, it is only fair to admit that steel has been used, and used successfully, for ship-building, off and on for many years, but I believe the success has been achieved only where the material has been very carefully selected, and due precautions have been taken in its use.

A large number of small vessels have, for instance, been built for special purposes of trade, and have done their work well; and even merchant ships, above 1,000 tons register, have been so constructed, and fully answered the expectations of their owners. One sailing ship of 1,200 register tons has been employed in general purposes of trade for the last fourteen years, and is so employed at present, and structurally has given every satisfaction.

These facts show that we are not altogether wanting in experience of steel for ship-building, even in ordinary sea-going ships. At the same time, it is only too true that in other attempts at steel ship-building very brittle plates have been found to be interspersed amongst others possessing every desirable quality, and this gave rise, and justly so, to the distrust which for a long time has been felt in using steel in an ordinary manner for general purposes of ship construction.

Experience has now, however, abundantly proved that mild steel can be manufactured either by the Bessemer or Siemens process, possessing qualities of ductility in connection with tensile strength and general uniformity, which render it much superior to the iron in ordinary use, and fully meriting the high praise which has been claimed for it by the manufacturers; and, what is of not less importance, this material can be produced at a comparatively cheap cost, thus rendering its adoption practicable.

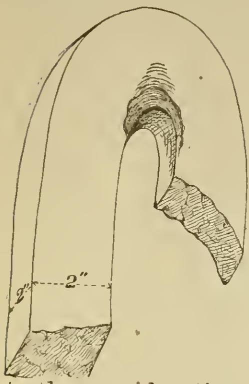
After most careful inquiries I have elicited but one opinion from those who have recently used it in ship-building, and those whose duty it has been to officially inspect the working of it, to which I can bear my personal testimony, that within certain limits of thickness it is a material which can be used with the greatest confidence under precisely the same conditions as would be required in the use of iron.

With a view, however, to have further information on the properties of this mild steel under the various conditions to which it would be subjected in the ordinary course of constructing merchant ships, the committee of Lloyd's Register have recently at considerable expense caused many series of experiments and tests to be made under the inspection of their officers, and I have much pleasure in laying the results of these before the meeting, together with some others furnished me of a trustworthy character. And I should say we feel much indebted to some of the principal steel manufacturers of Bolton, Sheffield, Scotland, and on the continent, for the assistance they have afforded us and the expense they have incurred in facilitating these inquiries.

These tests, it will be seen, embrace the qualities of the material as regards its tensile strength, elongation, effects of punching and drilling on steel plates, annealed and unannealed, as compared with iron; also the strength of riveted joints of steel plates as compared with iron, &c.

Information on some of these points already existed, but the tests were generally confined to thin plates and small samples, as in the tables of results furnished by Mr. Riley in the paper on steel read before the members of this institution in 1876, and in some of our own earlier tests. In the examples now given the tests have been extended to thicker and larger specimens of plates, whilst the tests on riveted joints and on punching are of more value from the fact of a comparison being made between steel and iron under the same conditions, which is of practical importance in dealing with this branch of the subject.

While this mild steel, as before said, is found to be sufficiently ductile for every purpose for which it may be required, and its uniformity of quality is admitted to be remarkably great, it is at the same time, with proper care, capable of being *welded* with as much ease and as satisfactorily as iron. This has been shown to the entire satisfaction of many of our surveyors, and quite recently in the case of one of them who has been conducting a series of experiments on steel at one of the principal steel manufactories on the continent. It is also confirmed, as will be seen by the specimen produced, which has been forwarded to me by Mr. Kirk, of Glasgow. The specimen was "shingled" from the cuttings of steel plates in ordinary use, in the same way and at the same heat as would be done with common scrap iron. It was bent, as you see it, cold, till the ends closed and finally broke. A piece of the same material



was tested and found to stand a tensile strain of 26 tons to the square inch. Mr. Kirk observes, "In all this it behaves just as ordinary iron. It welds as freely, and does not lose its strength by the process. In fact it is cleaner and more perfect in the welds than iron." This is very important, as considerable doubt still exists in many minds whether it can safely be used for forgings.

The question of the *qualities* of the material, however, is only one part of the subject in ship construction; another of equal importance is the *connection* of the several parts. And this leads to the consideration of the most fitting material for the rivets of steel ships, and the sizes and arrangements of the riveting. Although I believe the admiralty have not yet adopted steel rivets in ships built of steel for the royal navy, yet steel rivets have been used very satisfactorily in two steel vessels recently built by Messrs. Laird Brothers, of Birkenhead. They have also been adopted by Messrs. J. & G. Thompson, on the Clyde, in a large steel vessel building by them, with perfect success. In fact the latter gentlemen state they find less liability to injury from overheating in steel than in iron; but the rivet steel for this purpose was in both cases of a specially mild quality.

Experience has, however, shown that risks are incurred unless special means are adopted to insure the rivet steel being of a very mild quality, or that the rivets are uniformly heated, and at not too high a temperature.

To illustrate this, I may mention that the builders of a steel vessel, recently constructed, determined at first to adopt steel rivets. After one or two landing edges of the outside plating had been riveted, it was found by them that many of these rivets were broken off in the process, generally between the surfaces of the two plates they connected. In consequence of this the use of steel rivets was abandoned and iron rivets of the best quality substituted throughout the plating of the vessel.

If we could insure the efficiency of the steel rivets, their greater strength—which is shown to be one-fourth more to resist shearing than iron rivets of the same size and spacing—would enable us to obtain better joints, even with smaller rivets, if they were properly spaced; yet, if constant vigilance were required, where boys are employed to heat them in ordinary open furnaces, I should hesitate to advocate their general adoption. At the same time, when such satisfactory results as those referred to have been obtained, there does not appear to be much doubt that with steel specially prepared for the purpose, the rivets properly made, and with ordinary care in their use, satisfactory riveting can be made with steel rivets; and when the additional strength which they impart is considered, it becomes a matter of much importance that their use should not be unduly restricted, unless more evidence than we appear to have at present shows that danger is likely to result therefrom.

There is no doubt the question of riveting is still open to much consideration, and ample room is left for a most useful series of experiments as to the best diameter and pitch of rivets in relation to the thickness of the plates; effects of single, double, and treble riveting; also the comparative advantages of steel and iron rivets. I venture to express the hope that the admiralty, steel manufacturers, and others will be enabled to see their way to assist us in extending these tests in the direction indicated.

In Table I are given the results of some tests of the strength of iron and steel plates connected together by butt straps and with iron and steel rivets. The first nine of these in the table were kindly prepared for testing by Messrs. J. Elder & Co., and the following are the mean results:

First. Iron plates, connected together by iron butt straps of the same thickness, double chain riveted with iron rivets, and having the holes punched, show a mean tensile strength of 17.9 tons per square inch, and in all these cases the plate broke through the rivet holes.

Secondly. Steel plates, not annealed after punching, connected together by a steel butt-strap of the same thickness, double chain riveted with iron rivets, withstood a tensile strain of 16.7 tons per square inch of rivet area, the tension on the plate between the rivet holes being only 15.3 tons per square inch when the rivets sheared.

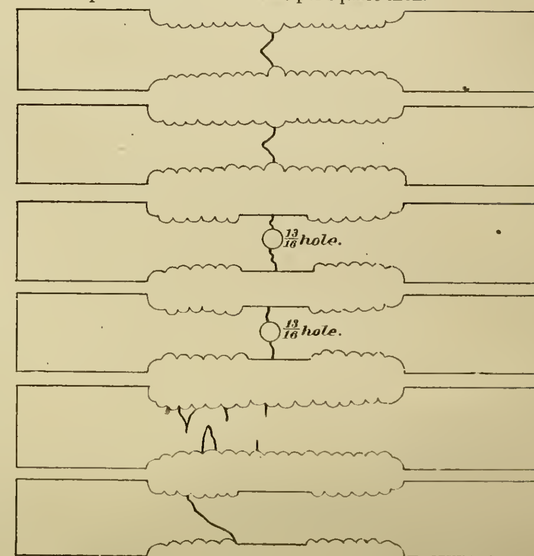
Thirdly. In a similar experiment to the foregoing, with the exception of the rivets being arranged zigzag instead of chain, the rivets were sheared at 19.2 tons per square inch, or a mean of 17.9 in the two experiments.

Fourthly. Steel plates, not annealed after punching, connected together by steel butt straps of the same thickness, double chain riveted with *steel* rivets, show a mean tensile strength of 22.5 tons per square inch—the rivets shearing in some cases and in others the plates breaking.

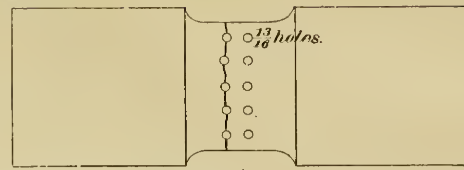
From these results it appears the full strength obtained from double riveting, with iron rivets, does not exceed a mean of about 18 tons per square inch. In view, therefore, of steel plates unannealed, as shown, withstanding a tensile strain of 22½ tons, at the rivet holes, double riveting with iron rivets is not sufficient to insure the strength of the

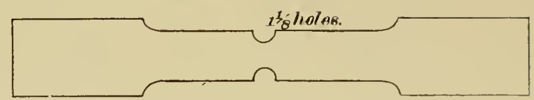
TABLE II.—*Steel: Showing loss of tensile strength due to punching, &c.*

No.	Dimensions.	Plain plates. Ultimate tension.	ULTIMATE TENSION.					Remarks.
			Number and diameter of rivet holes.	Punched and rimed.	Punched and annealed.	Punched and not annealed.		
		Tons per square inch.		Tons per square inch.	Tons per square inch.	Tons per square inch.	Loss from plain plate, per cent.	
	Inch. *Inch.*		*Inch.*					
1	$\frac{1}{4}$ plates, $5\frac{1}{2}$ broad	32.07	Two $\frac{5}{8}$	....	....	29.48	8.1	Punched with open die.
2	$\frac{1}{4}$ plates, $5\frac{1}{2}$ broad	....	Two $\frac{5}{8}$	....	29.1	29.0	....	
3	$\frac{9}{32}$ plates, $4\frac{3}{4}$ broad	28.06	Two $\frac{3}{4}$	....	26.15	23.79	15.2	A drilled specimen stood 24.83 tons per square inch.
4	$\frac{5}{16}$ plates, $4\frac{3}{4}$ broad	29.85	Two $\frac{3}{4}$	....	29.27	27.59	7.5	
5	$\frac{3}{8}$ plates, $1\frac{5}{8}$ broad	30.0	One $\frac{9}{16}$	....	26.5	26.8	10.6	
6	$\frac{3}{8}$ plates, $2\frac{11}{16}$ broad	28.43	One $\frac{5}{8}$	....	....	23.20	18.4	
7	$\frac{3}{8}$ plates, $6\frac{3}{4}$ broad	....	Two $\frac{3}{4}$	....	27.73	25.21	....	
8	$\frac{3}{8}$ plates, $6\frac{3}{4}$ broad	29.59	Two $\frac{13}{16}$	....	....	24.06	18.7	
9	$\frac{3}{8}$ plates, $2\frac{1}{8}$ broad	31.48	See sketch	....	....	31.18	....	
			Do	....	....	31.18	....	
			Do	....	....	29.9	5.0	
			Do	....	....	30.55	3.0	
			Do	....	....	28.18	10.4	
			Do	....	....	27.91	11.3	



10	7/16 plates, 3 broad	27.61	One	7/8	....	....	.2822	nil.	Holes were punched in plate that had been previously tested to rupture.
11	15/32 plates, 7¾ broad	28.98	Two	7/8	....	....	21.38	26.2	
12	15/32 plates, 16 broad	....	See sketch		....	28.4	25.1	....	
13	½ plates, 7¾ broad	....	Two	7/8	....	31.28	24.95	....	
14	½ plates, 7¾ broad	28.9	Two	7/8	....	30.5	27.84 (a) 27.54	3.7 4.8	(a) This specimen was punched and tested as it came from the rolls, being unannealed.
15	19/32 plates, 7¾ broad	29.55	Two	7/8	....	....	19.57	33.8	
16	5/8 plates, 7¾ broad	....	Two	7/8	....	27.92	23.28	....	
17	11/16 plates, 4 broad	27.05	See sketch		28.81	28.98	22.92	15.2	
18	11/16 plates, 4¼ broad	27.0	One	7/8	25.69	....	24.46 21.04	9.4 22.1	Very open die.
19	¾ plates, 8¼ broad	26.4	Two	7/8	28.2	31.71	20.0 18.69	24.2 28.7	Punched with close die. Punched with open die.
20	¾ plates, 8¼ broad	....	Two	7/8	21.72*	28.58	20.5 19.08	....	Punched with close die. Punched with open die.





* This specimen broke through pin-hole without signs of distress at the rivet holes.

plates being utilized ; and that in order to accomplish this, either the rivets should be larger or more closely spaced, or the butts would have to be *treble* riveted with iron rivets, or double riveting with steel rivets adopted.

Other experiments have been made on *punching* plates, both annealed and unannealed, and also by having holes drilled, and by punching and subsequently enlarging the holes by riming.

The results of these tests, as shown in Tables II, III, and IV are of great interest, as showing—

First. That steel plates very thin suffer less from punching than iron.

Secondly. That the difference in loss of strength by punching on steel and iron does not appear sufficiently great to require special precautions to be taken for steel more than for iron in plates up to eight-sixteenths of an inch in thickness.

Thirdly. That in plates above eight-sixteenths of an inch in thickness, the loss of strength of iron plates by punching ranged from 20 per cent. to 23 per cent., while in steel plates of the same thickness it ranged from 22 per cent. to 33 per cent. of the original strength of the plate between the rivet holes. An occasional plate both of iron and steel showed a smaller loss than the minimum here indicated, but they were exceptional cases so far as these experiments go.

Fourthly. That by annealing after punching the whole of the lost strength was restored, and in some instances greater relative strength was obtained than existed in the original plates.

Fifthly. That the steel was injured only a small distance around the punched holes, and that by riming with a larger drill than the punch, from one-sixteenth to one-eighth of an inch around the holes, the injured part was removed, and no loss of strength was then observable any more than if the hole had been drilled.

Sixthly. That in drilled plates no appreciable loss of tensile strength was observed.

From these conclusions the question arises, whether in using steel plates for ship-building, above eight-sixteenths of an inch in thickness, they should be annealed or the holes rimed after punching.

Here again we must fall back upon the comparison with iron. When we hear the complaint that steel loses so much by punching, it often escapes attention that iron also loses considerably by that operation, and that allowance must be made for this. If then we start with iron at a normal strength of 20 tons and steel at 28 tons per square inch, and suppose the reduction in scantlings for steel is 20 per cent. from those of iron, it can easily be shown that if the steel loses 30 per cent. by punching, and the iron 22 per cent., the balance of strength still remains slightly with the steel ; and this agrees pretty much with the experiments made on the strength of riveted joints.

The loss due to punching is nevertheless a most important matter, and serious attention should be given to mitigating it. Punching with an open die has been strongly recommended as a means of reducing it, and experiments are not wanting to support this view.

On the other hand, however, the recent experiments referred to do not sufficiently bear it out. Improvements in the mode of punching have been suggested, and there is probably much to be hoped for from an advance in this direction. In the mean-time there are other points which tell in favor of the steel ship. Practically, the holes in the outside strakes of plating have nearly all the distressed or injured parts around the hole removed by counter-sinking; and it would be easy to make this still more effective, so that under any circumstances there would remain in the skin of the vessel only the inner strakes of plating and the butt-straps to be dealt with.

When, however, it is considered that the probable cost of annealing all the outside plating, stringers, and butt-straps would not exceed a few shilling per ton of material in the ship, I cannot think it will form a serious impediment to the introduction of steel ship-building even if it be found indispensable. It would, I conceive, be better to make a somewhat greater reduction in the scantlings than to dispense with restoring the strength at the butts in large ships by annealing or riming the holes, or by some other such effectual means of achieving this object as may hereafter be devised. In the same way, it appears to me that in all ships where the sheer-strakes, garboard strakes, and deck stringer plates are above eight-sixteenths of an inch in thickness, they should, together with the butt-straps, be annealed after punching, in order to utilize, as far as possible, the full strength of the material at these important parts.

A step in the direction of rendering annealing or riming after punching unnecessary has, I am glad to say, been taken by the introduction of the patent spiral punch, from which results of a very encouraging nature appear to have been obtained. On reference to Table IV it will be seen that by the use of this punch the strength of the material after punching was about 2½ tons per square inch greater than by the use of the ordinary punch, whilst greater ductility was found to exist around the holes.

Not a bad indication of the merits of a punch is the smallness of the power required to drive it through the plate; this measures the work that has to be absorbed in the production of heat or distortion during the operation of punching. I have been supplied with particulars which go to show that the spiral punch requires only about two-thirds the force behind it that an ordinary punch does; and, besides this, it acts more injuriously on the piece punched out, and less so on the surrounding plate. Further improvements still may, it is hoped, be made in this direction.

Another point of importance in considering the reduction of scantlings in steel ships is the comparative rigidity of steel and iron. The efficiency of a ship must in all cases depend, in a great measure, upon her general rigidity, as well as upon her longitudinal strength, and it is important in making reductions in the sizes of the frames and reserve frames that this feature should be maintained. Also in reducing the thickness of the plating, especially towards the ends of a ship, it is necessary to think of its rigidity between the frames, and of the means of imparting strength to resist panting and distortion.

I have given the results of a few experiments intended to throw some light on this point, and they do not, so far as they go, speak so favorably for the steel as the tensile and other experiments do. They consisted in testing the comparative stiffness of strips of steel and iron plate, and of some plates and angles combined, by supporting the specimens near the ends and weighting them in the middle, and measuring the amount of deflection at successive loads. The test pieces were supported, but not rigidly held, by the ends, and so differed in a measure from the condition of the skin plating between the frames of a ship, and the steel might probably have compared somewhat better if the ends had been fixed. But the experiments which are shown in Tables V, VI, VII, and VIII, are, nevertheless, instructive as far as they go, and I hope we shall yet see more extensive and complete experiments in the same direction.

Another point of interest may be mentioned here. Some inconvenience having been found to exist from fixing a definite length on which the elongation under tensile strain should be measured, owing to the length not suiting some of the private testing machines, some experiments were made to ascertain how the percentage of extension varied with the length of the specimen, and in Table IX the percentages of extension in 2, 4, 6, and 8 inches are given, and may prove useful.

In treating of this subject of steel for ship-building it is not, as I have before intimated, sufficient to show the superior qualities of steel as compared with iron for ship-building purposes; but it is also necessary, before it will be generally adopted, to show that it can be profitably employed.

The number of people who would leave the beaten track and have their vessels built of a comparatively untried material like steel, simply on the faith or in the hope that they would thereby possess stronger vessels, and perhaps be liable to less risks of loss from collision, grounding, or other causes, would, I fear, be very small, unless it could be shown them either that they would not cost more than if built of iron or that a fair profit might be looked for from the additional outlay. This is not due to any want of appreciation of a superior vessel, or disregard to the increased safety to property and lives resulting therefrom, but simply from the hesitation people naturally feel to embark in a new thing, and from the necessity, if they wish to compete successfully, in these difficult times, of regarding the question from a business point of view.

It will therefore perhaps not be without interest to make a brief comparison of the cost of building iron and steel vessels at the present prices, and to endeavor to point out the advantages or otherwise of adopting the two descriptions of materials, allowing a reduction as admitted by the committee of Lloyd's register in the weight of steel as compared with iron.

A point having some bearing on this is that of the relative density of steel and iron; and in consequence of statements to the effect that there was a difference of as much as 4 per cent. between them, the steel being that much heavier than iron, I have endeavored to obtain trustworthy data upon the point. Messrs. John Brown & Co., of Sheffield, have very kindly made some experiments on the subject with the following results:

Boiler plate iron, average specific gravity, 7.618; pounds per cubic foot, 476.125.

Mild steel plates, average specific gravity, 7.820; pounds per cubic foot, 488.75.

Difference 2.66 per cent. steel heavier than iron.

I have also obtained some data from Mr. Bessemer, which shows still less difference between the weight of steel and iron, and I am therefore constrained to believe that the difference of 4 per cent. alleged is considerably above the mark.

It is evident that vessels engaged in carrying dead weight must realize greater advantage from the use of lighter scantlings than the ship carrying measurement goods. I have therefore selected for the purpose of comparison three types of vessel, viz:

First. A screw steamer suitable for the India trade.

Secondly. A sailing ship of about 1,700 register tons to be employed in general trade.

Thirdly. A screw steamer designed for dead-weight carrying in the ore trade.

The principal dimensions of the first of these vessels are: Length, 316 feet; breadth, 36 feet; hold, 25 feet 6 inches. Gross register tons 2,300, and of 200 horse-power.

Such a ship built of iron at the present time to class 100 A would cost complete for sea about £36,000, and would require about 1,090 tons net of iron. The following may be taken as a statement of a Bombay voyage:

Allowing 800 tons of coals for the ship's use, the cargo on which freight would be paid would be 2,200 tons, at 30*s*. per ton		£3,300
Homeward cargo, 3,500 tons measurement, goods at 40*s*. per ton		7,000
		10,300
Expenses on voyage	£7,300	
Insurance on £36,000 for four months, at 8 per cent. per annum	960	
		8,260
		2,040

Equivalent to a profit of, say, 5½ per cent. on the voyage.

Now, if we suppose a similar ship built of steel, of the decreased scantlings, and to class 100 A, to take about 890 tons net of steel, she would cost about £40,500, and the statement of a similar voyage would stand thus:

Allowing 800 tons for coals for ship's use, the cargo on which freight would be paid would be 2,400 tons, at 30s. per ton		£3,600
Homeward cargo, 3,500 tons measurement, goods at 40s. per ton		7,000
		10,600
Expenses on voyage	£7,300	
Insurance on £40,500 for four months, at 8 per cent. per annum	1,080	
		8,380
		2,220

Or a profit of about 5½ per cent. on the voyage.

As, however, it may occur that a dead-weight cargo out and home could be secured, such as coals out and rice home, the comparison in such a case would be different, and would show, as follows, a considerable advantage in favor of the steel ship:

IRON SHIP.

Cargo out (say coals), 2,200 tons, at 20s		£2,200
Rice home 2,700 tons, at 60s		8,100
		10,300
Expenses on voyage	£7,300	
Insurance at 8 per cent	960	
		8,260
		2,040

Or a profit on the voyage of, say, 5½ per cent.

STEEL SHIP.

Cargo out, (say coals), 2,400 tons at 20s		£2,400
Rice home, 2,900 tons, at 60s		8,700
		11,100
Expenses on voyage	£7,300	
Insurance at 8 per cent	1,080	
		8 380
		2,720

Or a profit on the voyage of, say, 6¾ per cent. as against 5½ per cent. for the iron ship.

If, now, we take an iron sailing ship of 1,700 gross register tons, to class 100 A, taking about 840 net tons of iron, she would cost about £22,000. A similar vessel built of steel would require about 680 net tons of steel, and would cost about £25,000.

The difference in the net weight of material or carrying capacity would consequently be about 160 tons.

A comparison cannot so easily be made in this case as in the former, as the conditions are more varied; but there does not appear to be much doubt that with a steel ship, properly designed and properly managed, she would, under ordinary circumstances, hold her own against the cheaper iron vessel, while with exceptional freights of full dead-weight cargoes out and home the additional 160 tons capacity would cause a balance to appear in her favor. I am not alone in this opinion, as a sailing ship of about 1,700 tons is now being built of steel, and the experienced and intelligent owner of her fully expects, whilst having a stronger and better ship, to be enabled to thus recoup himself for the additional outlay. However, those who, like myself, desire to see the general use of this superior material as a substitute for iron, can only hope that this commercial element, which at present is somewhat nicely balanced, will eventually declare itself still more clearly in favor of steel, so as to lead to its wholesale adoption for general shipbuilding purposes.

There is no doubt that for vessels intended for special trades, where a light draught of water is essential, and where the cargo consists entirely of dead weight, such as the ore and some other trades, the use of steel, even as the matter now stands, will be found most advantageous.

If we take a screw steamer suitable for the ore trade, to carry about 1,300 tons, and having a double bottom, she would cost complete for sea about £17,500. If built of steel, the cost complete would be about £19,000, and such a vessel would carry about 75 additional tons on the same draught of water.

As these vessels make a voyage a month, say at 15*s.* per ton, the gain per annum will be found to exceed 25 per cent. on the additional outlay, or 2 per cent. on the whole cost of the vessel.

Other illustrations might be given, but it is thought these are sufficiently typical to show that steel can be profitably used in building vessels for certain trades. In other trades, as will be observed, the case is more doubtful, and it will require some time and careful investigation before a full and complete knowledge of all the circumstances can be arrived at.

In connection with the question of cost there arises another—and that is, as to the *durability* of steel compared with iron. This is a branch of the subject of considerable importance, and is being much discussed at present. To show the extent to which many are interested on this point, I may mention that since a short paragraph appeared recently in the press relating to the alleged rapid deterioration of torpedo boats built of steel, I have had numerous inquiries in reference to this subject, not only from many interested in it in this country, but also from abroad.

I can quite understand its being desirable to use gun-metal or bronze in preference to either steel or iron for light swift torpedo boats, without drawing the conclusion that steel deteriorates much faster than iron; but this latter is an impression which has somehow got abroad from the paragraph in question, and I should therefore not be sorry to hear a few words on the subject from one or other of our admiralty friends, as they have doubtless made experiments and careful observations on this subject.

What information I have gained of the comparative deterioration of steel and iron from oxidation, is not such as to warrant the opinion which appears to be entertained by some that steel deteriorates much more rapidly than iron when used for ship-building.

The experience which has been gained of the performances of actual vessels built of steel cannot, therefore, fail to be of much value on this point. I have endeavored to obtain information relative to vessels built of this material which have been the longest in existence. A striking illustration is that of a paddle steamer, which was built on the Clyde in 1859, for the Pacific Steam Navigation Company, and has been employed in actual service up to the present time, and is, perhaps, the oldest steel vessel now afloat. She was examined about four years ago, and the bottom plating from the keel to the water-line was, I understand, found to be in a state of excellent preservation. In the vicinity of the water-line, where deterioration would naturally be expected, the plates were found to be wasted, but not more than might have been the case under the same circumstances with iron plating.

Another case is that of the steel sailing ship of 1,200 tons, before alluded to. This ship has been engaged in general trade to India and elsewhere for the last fourteen years, and I am informed when last surveyed she was not found to have deteriorated even to the extent which would have been experienced in an iron vessel under the same circumstances.

In corroboration of this I may mention that when conversing with Mr. Bessemer very recently on this subject, he informed me that he had made experiments with a view to ascertain the comparative corrosion of steel and iron in nitric acid, and that the results would seem to bear out this experience.

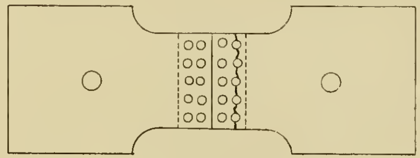
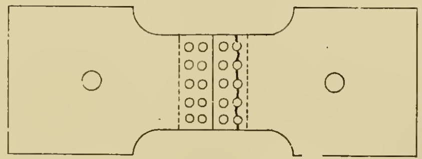
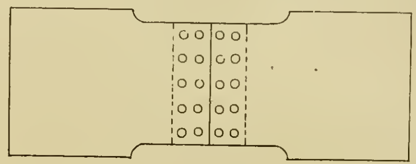
I have, it is true, heard of light-draught river boats, built of steel, deteriorating rapidly, but have not yet been able to clear my mind of a suspicion that either the speciality of the cargo, or the nature of the waters navigated, or some such surrounding circumstances, such as carelessness, might have aggravated the wasting alleged to have taken place in them.

I may mention also that there are two steamers over 1,600 tons at present running between this country and the continent, which are built of steel. They were built in 1865, and have therefore been afloat the last thirteen years. Other cases might be mentioned of steel vessels which have been running for some years without leading to the conclusion that there is more rapid deterioration in steel than in iron, if the vessels be properly coated and attended to.

At the same time, owing to the smaller comparative scantlings, it is a matter of greater importance in steel than in iron ships, and having in mind the evils arising from negligence in iron vessels, the attention of ship-owners cannot be too strongly drawn to the false economy of running their vessels too continuously instead of placing them in dry dock at fitting intervals, so that the surfaces of plating can be properly examined, scraped, and painted when found necessary. By a due regard to this, whether the vessels be of iron or steel, my experience leads me to the conclusion that often much unnecessary outlay might be avoided, and the cost of detention and coating would be far more than compensated for by the durability of the vessels.

Many other points, and doubtless new ones, will arise in any general application of this material, and these we must be prepared to meet and overcome, and I feel sure nothing will be wanting on the part of the ship-builders of this country in adapting their appliances and modifying their practice to suit the requirements of any advance in the art of ship-building or in the material to be employed by them. If steel is to replace iron in the immediate future, I need not say the stride will be an enormous one, and great changes may have to follow, but I nevertheless look forward to such changes without misgivings, for I know they will be undertaken with the utmost care, and with every endeavor to abide strictly by the teachings of experience and with a due regard to the principles involved therein.

TABLE I.—*Tensile tests of riveted joints of steel and iron plates.*

Number.	Thickness of plates.	Width of specimen.	Description.	Thickness of straps.	Diameter of rivets.	Ultimate breaking strain in tons per square inch.	Remarks.
	Inch.	*Inches.*		*Inch.*	*Inches.*		
1	$\frac{1}{4}$	$13\frac{3}{8}$	Iron plates Single iron strap Iron rivets. Holes punched 	$\frac{1}{4}$	$\frac{5}{8}$	23.1	Broke through line of rivet-holes in plate.
2	$\frac{3}{8}$	$13\frac{3}{8}$	Iron plates Single iron strap Iron rivets. Holes punched 	$\frac{3}{8}$	$\frac{5}{8}$	16.8	Do.
3	$\frac{3}{8}$	$13\frac{3}{8}$	Steel plates not annealed Steel strap, not annealed Steel rivets Holes punched 	$\frac{3}{8}$	$\frac{5}{8}$	21.6	Rivets sheared.

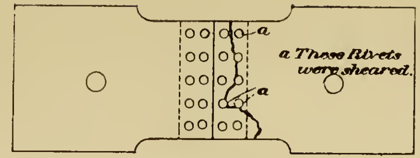
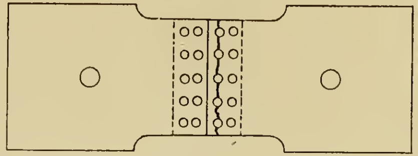
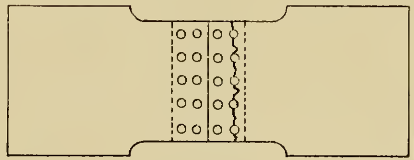
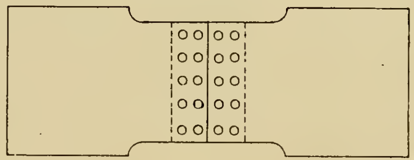
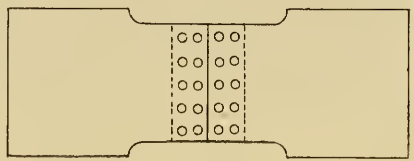
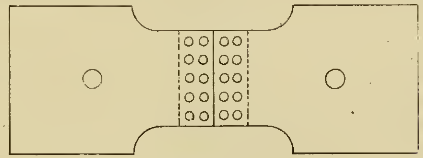
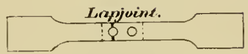
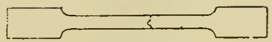
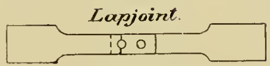
4	$\frac{15}{32}$	$16\frac{1}{4}$	Steel plates annealed after punching...... Steel strap annealed after punching....... Steel rivets.......................... Holes punched..........................		$\frac{15}{32}$	$\frac{3}{4}$	22.9	Broke through rivet-holes in plate.
5	$\frac{15}{32}$	$16\frac{1}{8}$	Iron plates.......................... Iron strap, single..................... Iron rivets.......................... Holes punched..........................		$\frac{17}{32}$	$\frac{3}{4}$	16.9	Broke through line of rivet-holes in the strap.
6	$\frac{1}{2}$	16	Iron plates.......................... Iron strap.......................... Iron rivets.......................... Holes punched..........................		$\frac{1}{2}$	$\frac{3}{4}$	15	Broke through line of rivet-holes in plate.
7	$\frac{1}{2}$	$16\frac{1}{8}$	Steel plates not annealed after punching.. Steel strap not annealed after punching... Iron rivets.......................... Holes punched..........................		$\frac{1}{2}$	$\frac{3}{4}$	16.7	Rivets sheared.
8	$\frac{1}{2}$	$15\frac{7}{8}$	Steel plates not annealed after punching.. Steel strap not annealed after punching.. Steel rivets.......................... Holes punched..........................		$\frac{15}{32}$	$\frac{3}{4}$	23.3	Do.

TABLE I—Continued.

Number.	Thickness of plates.	Width of specimen.	Description.	Thickness of straps.	Diameter of rivets.	Ultimate breaking strain in tons per square inch.	Remarks.
9	$\frac{1}{2}$	16	Steel plates annealed after punching..... Steel strap annealed after punching ...... Iron rivets.......... .... Holes punched.......................... 	$\frac{1}{2}$	$\frac{3}{4}$	17.1	Rivets sheared.
10	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates annealed after punching...... Iron rivets............................... Holes punched.......................... 	....	$\frac{3}{4}$	30.7	Broke plate through a rivet-hole.
11	$\frac{3}{8}$	$2\frac{1}{16}$	Steel plates annealed after punching..... Steel rivets .... Holes punched.......................... 	....	$\frac{3}{4}$	31.4	Do.
12	$\frac{3}{8}$	$1\frac{1}{2}$	Steel plate, plain......................... 	......	....	27.5	
13	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching.. Iron rivets.................................. Holes punched. Edges filed .... 	....	$\frac{3}{4}$	30.8	Broke plate through a rivet-hole.
14	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching.. Steel rivets......................... ... ... Holes punched. Edges filed .... 	....	$\frac{3}{4}$	30.6	Do.
15	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching.. Iron-rivets.................... .... Holes punched. Edges filed .... 	....	$\frac{3}{4}$	30.7	Do.

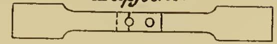
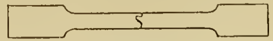
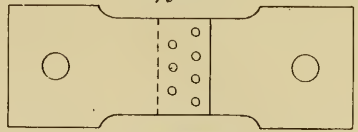
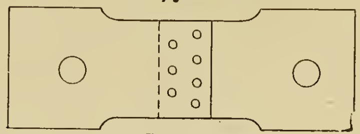
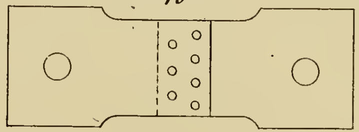
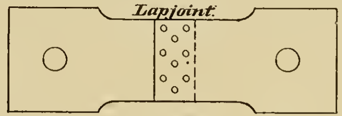
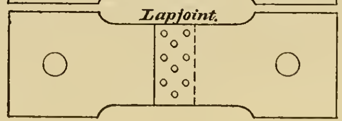
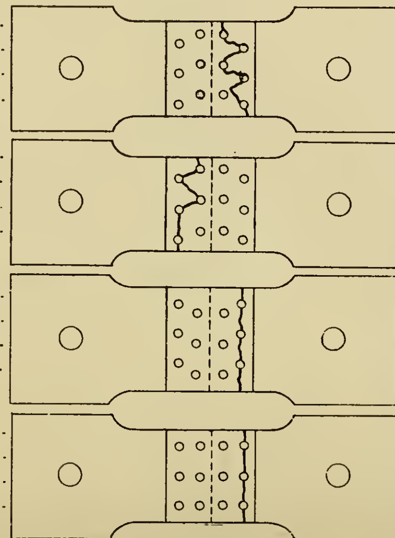
	$\frac{3}{8}$	$2\frac{1}{8}$	Steel plates not annealed after punching.. Steel rivets .... Holes punched. Edges filed	*Lapjoint.* 	....	$\frac{3}{4}$	30. 8	Do.
17	$\frac{3}{8}$	$1\frac{1}{2}$	Steel plate, plain.....................		....	....	30. 8	
18	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed..................... Steel rivets.......................... .... Holes punched............................	*Lapjoint.* 	....	$\frac{13}{16}$	24. 1	Rivets sheared.
19	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed. .... Steel rivets .... Holes drilled	*Lapjoint.* 	....	$\frac{13}{16}$	24. 25	Do.
20	$\frac{13}{32}$	$12\frac{1}{8}$	Steel plates not annealed ... . Iron rivets (Lowmoor) .... Holes punched	*Lapjoint.* 	....	$\frac{13}{16}$	19. 2	Rivets broke with ragged fractures at or near head or snap.
21	$\frac{13}{32}$	1	Steel plate, plain		....	....	{ 29 28. 4	
22	$\frac{9}{16}$	10	Steel plates...................................... Steel rivets .... Holes drilled.......................................	*Lapjoint.* 	....	$\frac{3}{4}$	27. 4	Rivets sheared.
23	$\frac{9}{16}$	10	Steel plates .... Steel rivets...................................... Holes drilled	*Lapjoint.* 	....	$\frac{3}{4}$	26. 7	Do.

TABLE I—Continued.

Number.	Thickness of plates.	Width of specimen.	Description.	Thickness of straps.	Diameter of rivets.	Ultimate breaking strain in tons per square inch.	Remarks.
	Inch.	*Inches.*		*Inch.*	*Inches.*		
24	$\frac{11}{16}$	12	Steel plates Holes drilled Double butt straps of steel Steel rivets	$\frac{1}{2}$	$1\frac{1}{16}$	24.6	Broke plate through line of rivet-holes.
25	$\frac{11}{16}$	12	Steel plates Holes drilled Double butt straps of steel Steel rivets	$\frac{1}{2}$	$1\frac{1}{16}$	23.1	Do.
26	$\frac{11}{16}$	12	Steel plates Steel rivets Double butt straps of steel Holes drilled	$\frac{1}{2}$	$1\frac{1}{16}$	28.7	Do.
27	$\frac{23}{32}$	$12\frac{7}{8}$	Steel plate Steel rivets Double butt straps of steel Holes drilled	$\frac{9}{16}$	$1\frac{1}{16}$	26.2	Do.



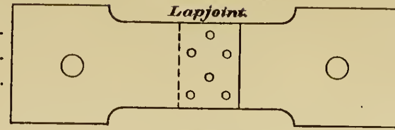
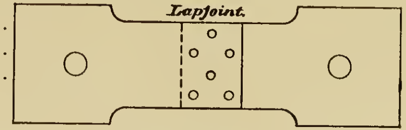
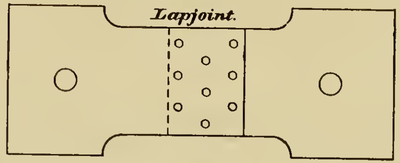
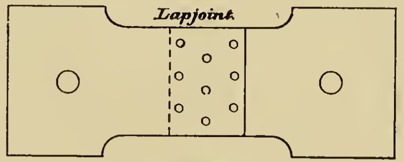
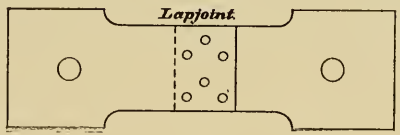
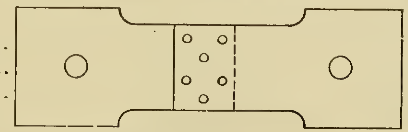
28	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .... Steel rivets .... Holes drilled		....	$1\frac{1}{16}$	19.7	Rivets sheared.
29	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .... Steel rivets .... Holes drilled		....	$1\frac{1}{16}$	19.7	Do.
30	$\frac{3}{4}$	$13\frac{1}{2}$	Steel plates .... Steel rivets .... Holes drilled		....	1	22.2	Do
31	$\frac{3}{4}$	$13\frac{1}{2}$	Steel plates .... Steel rivets .... Holes drilled		....	$1\frac{1}{8}$	21.9	Do.
	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates .... Steel rivets .... Holes drilled		....	$1\frac{1}{32}$	22.0	Do.

TABLE I—Continued.

Number.	Thickness of plates.	Width of specimen.	Description.	Thickness of straps.	Diameter of rivets.	Ultimate breaking strain in tons per square inch.	Remarks.
	Inch.	*Inches.*		*Inch.*	*Inches.*		
33	$\frac{3}{4}$	$11\frac{1}{4}$	Steel plates................................. Steel rivets................................. Holes drilled................................. 	....	$1\frac{1}{32}$	23.3	Rivets sheared.

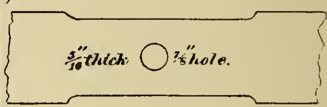
NOTE.—Where the riveting is zigzag the center of gravity of the area torn through does not fall in the line of the resultant tension. The stress is, therefore, unequally distributed and the stress on the material at the point where fracture commen·es must be greater than the mean stress given in the above table.

TABLE III.—*Iron: Showing the loss of tensile strength due to punching.*

No.	Dimensions.		Plain plates, ultimate tension.	Ultimate tension.						Remarks.
			Tons per square inch.	Number and diameter of rivet holes.		Punched and rimed.	Punched and annealed.	Punched and not annealed.		
	Thickness, inch.	*Width, inch.*			*Inch.*	Tons per square inch.	Tons per square inch.	Tons per square inch.	Loss from plain plate, per cent.	
1	$\frac{1}{4}$	$5\frac{1}{2}$	16.0	Two	$\frac{5}{8}$	....	....	14.0	12.5	
2	$\frac{5}{16}$	$4\frac{3}{4}$	19.33	Two	$\frac{3}{4}$	....	18.25	16.62	14.0	A drilled specimen broke at 17.74 tons.
–3	$\frac{3}{8}$	$6\frac{1}{4}$	21.7	Two	$\frac{3}{4}$	....	....	17.3	20.3	
4	$\frac{7}{16}$	3	21.81	One	$\frac{5}{8}$	....	....	17.37	20.3	
5	$\frac{1}{2}$	$7\frac{3}{4}$	20.1	Two	$\frac{7}{8}$	....	....	16.5	17.9	
6	$\frac{1}{2}$	$7\frac{3}{4}$	15.2	Two	$\frac{7}{8}$	....	....	14.0	7.8	
7	$\frac{5}{8}$	$7\frac{3}{4}$	17.4	Two	$\frac{7}{8}$	....	....	16.6	4.5	
8	$\frac{5}{8}$	$7\frac{3}{4}$	18.6	Two	$\frac{7}{8}$	....	....	14.6	21.5	
								15.59	21.7	Punched with open die.
9	$\frac{3}{4}$	$8\frac{1}{4}$	19.92	Two	$\frac{7}{8}$	17.66	19.13	15.90	20.0	Punched with close die.
								15.3	23.2	Do.
			24.88	....		....	....	....	....	A drilled specimen stood 19.11 tons per square inch.
10	$\frac{3}{4}$	4	22.53	One	$\frac{7}{8}$	21.17	....	18.19	20.4	A drilled specimen stood 22.57 tons per square inch.
			22.56	....		....	....	18.93		

TABLE IV.—*Results of experiments on the tensile strength of samples of the same steel plate punched with flat and patent spiral punches respectively.*

Diameter of hole.	Breaking weight. Actual.	Breaking weight. Per square inch.	Elongation. On two inches of length across the holes.	Elongation. Per cent.	Area of plate under tension.	Remarks.
Inch.	*Pounds.*	*Pounds.*				
.885	45,350	63,752	.11	5.5	.7114	Punched with the "flat punch."
.885	45,000	60,318	.23	11.5	.7461	
.895	42,400	57,495	.14	7.	.7375	
.89	37,000	51,287	.03	1.5	.7224	
.89	42,800	60,692	.06	3.	.7052	
.90	45,150	61,047	.07	3.5	.7396	
.895	39,000	55,465	.09	4.5	.7032	
Mean ...	42,393 or 18.9 tons	58,579 or 26.1 tons	.104	5.2	.7236	
.885	45,850	63,285	.27	13.5	.7245	Punched with "patent spiral punch."
.88	48,000	67,672	.25	12.5	.7093	
.88	46,200	63,584	.23	11.5	.7266	
.88	44,250	61,254	.12	6.	.7224	
.88	45,500	64,148	.26	13.	.7093	
.895	47,600	66,084	.27	13.5	.7203	
.885	45,600	61,476	.09	4.5	.7418	
Mean	46,143 or 20.6 tons	63.929 or 28.5 tons.	.21	10.6	.7220	



With seven additional experiments that were made, in which two holes were punched in each specimen, one with the "flat punch" and one with the "spiral punch," all the specimens broke through the hole punched with the "flat punch."

The spiral punch referred to is the "patent spiral punch," manufactured by Messrs. Thompson, Sterne & Co.

	Tons.	Tons.
NOTE.—A $\frac{7}{8}$ oval spiral punch penetrated a $\frac{5}{8}$-in. iron plate at a pressure of	22 and	25.
A $\frac{7}{8}$ oval flat punch penetrated a $\frac{5}{8}$-in. iron plate at a pressure of	33 and	35.

RIGIDITY TESTS.

TABLE V.—*Comparative rigidity of $\frac{6}{16}$ inch steel and $\frac{7}{16}$ inch iron plates.*

[Both specimens were 4 feet long by 6 inches wide. The bearings were 3 feet apart.]

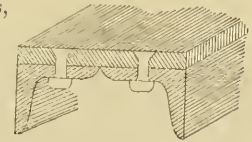
Load.	Deflection of the iron plate.	Deflection of the steel plate.	Permanent set in the iron plate.	Permanent set in the steel plate.
Cwt.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1	$\frac{1}{8}$	$\frac{3}{32}$	none.	none.
2	$\frac{1}{4}$	$\frac{7}{32}$	do.	do.
3	$\frac{11}{32}$	$\frac{11}{32}$	trace.	do.
4	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{16}$ bare.	do.
5	$\frac{9}{16}$	$\frac{21}{32}$	....	trace.
6	$\frac{23}{32}$	$\frac{13}{16}$	....	perceptible.
7	$\frac{27}{32}$	$1\frac{5}{32}$	....	....
8	$1\frac{3}{32}$	$1\frac{13}{32}$	....	....
9	$1\frac{19}{32}$	$1\frac{23}{32}$	$\frac{21}{32}$	$\frac{1}{2}$ full.
10	$2\frac{31}{32}$	$4\frac{15}{16}$	....	....
11	$5\frac{15}{32}$	....	....	....

	Inches.
Permanent set of the iron plate on being entirely released	$6\frac{7}{8}$
Permanent set of the steel plate on being entirely released	$6\frac{3}{16}$

TABLE VI.—*Comparative rigidity of steel and iron plates.*

Description.			Load.	Distance of bearings apart.	Deflection.	Permanent set.	Elongation.
	Inches.	*Inches.*	*Pounds.*	*Feet.*	*Inches.*	*Inches.*	*Inches.*
Steel plate	4	by $\frac{5}{16}$ ..	987	2	$3\frac{1}{2}$	$2\frac{1}{2}$	....
Iron plate	4	by $\frac{3}{8}$ ..	1, 001	2	$3\frac{3}{8}$	$2\frac{3}{4}$	....
Steel plate	4	by $\frac{3}{8}$ ..	1, 666	2	$3\frac{7}{16}$	$2\frac{11}{16}$	$1\frac{13}{16}$
Iron plate	4	by $\frac{1}{2}$ ..	1, 638	2	$3\frac{7}{16}$	$3\frac{1}{8}$	$\frac{13}{16}$

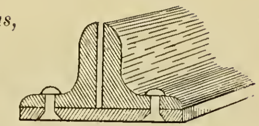
RIGIDITY TESTS.

TABLE VIII—*Iron and steel plates and angles riveted together thus,*  *supported at the ends and weighted in the middle.*

[Bearings, 3 feet apart; pitch of rivets, 4 inches.]

Load.	Test No. 1. STEEL.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles, $2\frac{3}{4}$ by $2\frac{3}{4}$ inches by $\frac{5}{16}$ inches.		Test No. 2. IRON.—Plate $6\frac{1}{4}$ by $\frac{7}{16}$ inches; angles, $2\frac{15}{16}$ by $2\frac{15}{16}$ by $\frac{3}{8}$ inches.		Test No. 5. STEEL.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles, $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{5}{16}$ inches.		Test No. 6. IRON.—Plate $6\frac{1}{4}$ by $\frac{7}{16}$ inches; angles, $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{3}{8}$ inches.		Test No. 9. IRON.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles, $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{5}{16}$ inches.	
	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.
Cwt.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
4	....	....	....	....	.015	.0012	.0185	.005	.025	.010
5	.0125	.0	.018	.0015	.0166	.004	.025	.005	.0275	.0108
7	.021	.0057	.025	.0057	.022	.0057	.0265	.0058	.036	.0111
10	.037	.009	.038	.0112	.032	.008	.0399	.008	.044	.0116
15	.052	.013	.057	.0190	.048	.012	.056	.0112	.063	.0165
20	.065	.016	.075	.0255	.063	.0165	.078	.014	.086	.018
25	.084	.021	.085	.0256	.078	.0218	.090	.0168	.098	.0215
30	.096	.025	.100	.0257	.084	.0255	.100	.021	.118	.0235
35	.107	.027	.107	.026	.107	.029	.117	.022	.135	.0255
40	.120	.032	.111	.026	.119	.031	.136	.023	.140	.027
45	.132	.035	.118	.027	.130	.033	.140	.026	.155	.0315
50	.142	.039	.130	.027	.142	.038	.155	.027	.167	.035
55	.159	.041	.138	.028	.159	.040	.160	.0315	.175	.040
60	.170	.048	.144	.031	.166	.043	.180	.033	.200	.044

65	.190	.051	.157	.031	.188	.051	.200	.042	.210	.058
70	.209	.056	.166	.035	.200	.056	.215	.050	.240	.068
80	.240	.067	.180	.038	.240	.070	.260	.073	.335	.166
90	.280	.080	.200	.040	.310	.111	.330	.130	.530	.305
100	.330	.130	.228	.051	.390	.150	.430	.210	.770	.490
110	.460	.231	.290	.080	.550	.305	.570	.330	.97	.75
120	.648	.383	.335	.158	.770	.555	.750	.480	1.31	1.08
130	.840	.580	.440	.220	1.02	.73	.96	.720	1.87	1.63
140	1.46	1.20	.590	.37	1.66	1.35	1.18	.960	Did not carry $6\frac{3}{4}$ tons. Plate broke through rivet-holes.	
150	1.98	1.74	.710	.50	2.44	2.15	1.50	1.22		
160	Did not carry.		.860	.64	Plate broke through the punched holes. Did not carry $7\frac{3}{4}$ tons.		1.96	Not taken.		
170	....		1.04	.80			2.43	..... do.....		
180	....		1.24	Not taken			3.14	..... do.....		
190	....		1.58	..... do.....	....		Plate broke through rivet-holes. Did not carry $9\frac{1}{4}$ tons.			
200	....		1.85	..... do.....	....					
210	....		2.31	..... do.....	....					
220	....		3.32	..... do.....	....					
			Plate broke across both punched holes.							

TABLE VIII.—*Iron and steel plates and angles riveted together thus,*  *supported at the ends and weighted in the middle.*

[Bearings 3 feet apart; pitch of rivets, 4 inches.]

Load.	Test No. 3. STEEL.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles $2\frac{3}{4}$ by $2\frac{3}{4}$ by $\frac{5}{16}$ inches.		Test No. 4. IRON.—Plate $6\frac{1}{4}$ by $\frac{7}{16}$ inches; angles $2\frac{15}{16}$ by $2\frac{15}{16}$ by $\frac{3}{8}$ inches.		Test No. 7. STEEL.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{5}{16}$ inches.		Test No. 8. IRON.—Plate $6\frac{1}{4}$ by $\frac{7}{16}$ inches; angles $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{3}{8}$ inches.		Test No. 10. IRON.—Plate $6\frac{1}{4}$ by $\frac{3}{8}$ inches; angles $2\frac{5}{8}$ by $2\frac{5}{8}$ by $\frac{5}{16}$ inches.	
	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.	Deflection.	Permanent set.
Cwt.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
2	....	....	....	....	.009	Perceptible.	.0031	None per-	.006	.0012
5	.019	.0012	.0125	.004	.019	.0013	.0114	ceptible.	.0165	.0052
10	.038	.0057	.032	.0058	.0315	.0027	.023	.00077	.033	.009
15	.060	.0114	.042	.0058	.051	.012	.036	.005	.046	.011
20	.075	.015	.056	.0112	.065	.016	.048	.0057	.060	.016
25	.084	.018	.063	.0112	.070	.0168	.063	.0075	.076	.017
30	.107	.021	.080	.0112	.096	.0169	.080	.0100	.090	.021
40	.132	.025	.096	.016	.125	.0210	.098	.0111	.110	.025
50	.158	.029	.130	.022	.144	.025	.128	.0165	.140	.030
60	.190	.0315	.140	.0255	.175	.030	.140	.0255	.159	.036
70	.210	.033	.159	.030	.200	.040	.170	.035	.190	.060
80	.240	.042	.190	.036	.225	.045	.200	.053	.330	.150
90	.270	.056	.235	.049	.260	.056	.240	.068	.500	.306
100	.336	.080	.250	.070	.305	.107	.320	.130	.800	.590
110	.480	.209	.320	.170	.430	.200	.430	.215	1.18	.95

120	.690	.400	.460	.210	.665	.405	.590	.350	2.00	1.77
130	.870	.630	.580	.336	1.180	.93	.81	.56	Did not carry 6¾ tons. Both angle irons torn from edge to root.	
140	1.32	1.02	.750	.490	1.73	1.47	1.18	.92		
150	1.86	1.61	1.07	.84	Split at 140 cwt. outside edge of angle through the rivet-hole.		1.65	1.39		
160	3.42	3.08	1.24	1.00			2.51	2.22		
170	Angle broke through rivet-hole.		1.58	1.30			3.82	Not taken.		
							Angle iron did not carry 175 cwt. Torn from edge to root.			
180	....	....	2.15	Not taken.						
190	....	....	3.10	......do						
200	....	....	5.08	......do						
210	....	....	Did not carry 210 cwt.							

TABLE IX.—*Tensile strains and extensions of steel plates ½ inch thick.*

Number.	Sizes.		Ultimate stress per sq. inch.	Original length.	Extension.		Remarks.
	Inches.	*Area in sq. in.*	*Tons.*		*Inches.*	*Per cent.*	
1	1.41 by .515	.726	27.2	8	2.31	28.9	Mean extension of four pieces, each 8 inches in length, 27.5 per cent.
2	1.415 by .51	.721	27.6	8	2.12	26.5	
3	1.415 by .51	.721	27.4	8	2.06	25.7	
4	1.415 by .52	.735	27.0	8	2.31	28.9	
5	1.32 by .52	.686	27.2	6	1.875	31.2	Mean extension of four pieces, each 6 inches in length, 29.4 per cent.
6	1.34 by .52	.696	27.1	6	1.875	31.2	
7	1.33 by .525	.698	27.2	6	1.58	26.4	
8	1.35 by .53	.715	26.9	6	1.735	28.9	
9	1.40 by .515	.721	27.4	4	1.265	31.6	Mean extension of four pieces, each 4 inches in length, 32.0 per cent.
10	1.40 by .52	.728	27.3	4	1.235	30.8	
11	1.41 by .52	.733	27.1	4	1.37	34.2	
12	1.415 by .525	.742	27.2	4	1.26	31.5	
13	1.37 by .525	.719	27.1	2	.812	40.1	Mean extension of four pieces, each 2 inches in length, 37.3 per cent.
14	1.36 by .515	.700	27.5	2	.735	36.7	
15	1.39 by .52	.722	27.4	2	.765	38.2	
16	1.41 by .52	.733	27.1	2	.687	34.3	

Table showing rates of extension of equal intervals in length of a steel plate ½ inch thick.

Number.		Actual extension.	Extension.
		Inches.	*Per cent.*
1	Extension in the 2 inches adjoining the fracture	.921	46.05
2	Extension in the next 2 inches of the length of specimen	.527	26.35
3	Extension in the next 2 inches of the length of specimen	.424	21.2
4	Extension in the next 2 inches of the length of specimen	.328	16.4

DISCUSSION.

Mr. HENRY MORGAN (member of Council). My lord, I should wish to make just one remark upon the paper which we have just heard. So far as the admiralty experience is concerned we have no reason to think that steel will deteriorate faster than iron. The fact that we are building for experiment a torpedo boat of brass must not be interpreted as implying that for that purpose steel will not last as well as iron, supposing both to be equally taken care of. The meeting will readily understand that with regard to a plate of steel one-sixteenth inch thick we absolutely cannot afford to lose any; that while taking off one-sixteenth inch from iron plates of one-half inch in thickness would be of comparatively small consequence it would be of fatal effect on plates only one-sixteenth inch thick. That is the reason why we are resorting experimentally to the use of brass in building a torpedo boat.

Mr. J. D'Aguilar Samuda, M. P. (vice-president). I only desire to say in reference to the paper put before us that I concur entirely in that which it intends to advocate, namely, a substitution, almost a universal substitution, of steel for iron in ship-building, because I believe we are approaching very rapidly to that point. The experiences which are given in this paper are in many instances very valuable, but there are some matters on which probably some extra experience would be advantageous. First, with reference to the comparative durability of steel and iron. I can go from experience far beyond what this paper gives us, even the very extended one of the Pacific navigation in 1859. I can give the Institution an instance of a vessel of 500 tons built by myself in 1865, which I watched very carefully, and I found the deteriorition there wholly unimportant. Of course the Institution will understand that it is absolutely necessary, both in steel and iron, that each should be properly preserved by painting. If that is neglected, with regard to the thinner description of steel, there would be a worse result than with the thicker description of iron before it was rendered absolutely useless, but I believe, as far as I have been able to observe, that there is considerably less destruction from rust in the steel than in the iron when both are equally submitted to it. Another point which I particularly desire to draw attention to is this: It appears from Mr. Martell's experience, and from the experience of others which he has quoted, that steel is not getting at all a fair chance of being introduced to the extent to which it ought to be from some prevailing impression that seems to exist that steel rivets are not easily and successfully used. In this very vessel which I have alluded to, which has been built now for twenty-four or twenty-five years, there is not a single rivet but what is made of steel, and although I have sent repeatedly—the vessel is working now in the Sea of Azof and the Black Sea—and have had repeated reports from the man in charge of the vessel, not a single instance has been reported to me of any of the rivets having failed. There is no doubt that the failure one would look for from steel would be such a thing as the breaking off of the heads of rivets, but that might be absolutely provided against by carrying out the conical shape of the rivet as is generally done now in the skin-plating of ships, and, if necessary, extending that operation, and counter-sinking, also to the plates in the inside, where that could be done, so as to make the rivet terminate not in an extended head, but in a gradually enlarged diameter. Now, I think there is no justification whatever for holding to the idea that you cannot have steel rivets, and the experiments which have been put before us show in every instance how completely you nullify the use of steel by reducing it back again to the strength of the iron, as, in nine cases out of ten, the experiments show that the rivets are the first to give way, and that that is the ultimate strength that you have in your ship. Those are matters which are very important. Now, there are two or three things which I think should be explained in this paper, and perhaps Mr. Martell will be kind enough to explain them when he speaks again. You must recollect that the steel which is used in the present day is a very different material from the steel used formerly, and when steel is referred to as having been used it is desirable that we should know, both for the benefit and the disadvantage of the steel then produced, what description of steel it was. The steel which I refer to—used in 1854 by myself—was an extremely expensive steel, absolutely cast steel made in the same way as tool steel. That cost at that time £50 a ton, but although it cost that it was no better than steel which you can get at this moment for something like £13 a ton. But then, intermediately between those two prices, there has been quite a different steel used which I do not think can be relied on to the same extent, and that is puddled steel. From 1862 to 1870 puddled steel was used rather extensively, and I rather think most of the vessels Mr. Martell referred to were built of puddled steel, certainly some of them were. But I can say even with puddled steel a deal of difference existed, and from 1862 to 1865 I myself used puddled steel very extensively in vessels which I built. Five of those are running at this moment; three of them have lasted perfectly, the other two have not, and I believe that a great deal of discredit has arisen to steel in comparison with iron from the fact that steel vessels built about that period did not have the advantage of the best description of material. At any rate, the material which we have to deal with now is totally different; it is a reliable material where you can measure the component parts you put together accurately, and it is very different from what takes place with puddled steel where the man's eye and hand had only to be depended upon for terminating the operation at the time when a sufficient quantity of carbon was discharged from it. You cannot compare puddled steel vessels with those you get from the Bessemer or the Landore steel process which is in use at this moment. I am very glad to hear that the admiralty maintain the same opinion that they had last year with reference to steel. I think myself the advantages of it are even greater than those put forward in this paper, because I do not think those advantages are to be measured absolutely by the amount of money, but by something very much further than that, the amount of sustaining quality which we should find from its great ductility whenever it came into positions of very serious difficulty. Be that as it may, I am sure it is a matter which deserves the greatest possible attention of this Institution, because I think with ships and rails, and generally, we are quickly passing from the stage of manufacturing iron into that of manufacturing steel as an entire substitute for it.

Mr. C. Hampden Wigram (member of Council). My lord, Mr. Samuda has referred to steel rivets, and I entirely agree with him in what he has said. He will remember that some of the ships he refers to which he built—and we built others at the same time—were built entirely with steel rivets, with the holes counter-sunk on both sides right through the plate. Some of those vessels are running now for the Chatham and Dover Railway, and we had no difficulty in heating or from breaking of the rivets, although we employed the usual rivet boys; we did not spoil more rivets than is usual with iron, and in no way could I see that the steel rivets had deteriorated. Two years afterwards one of these vessels ran against Dover Pier, and knocked her nose completely on one side. She came up to London, and we had to repair her, and so far from the rivets being deteriorated or of inferior quality, we had the greatest possible difficulty in cutting out those rivets. Ordinary steel tools were of no use at all; they broke off in no time, with three or four blows, and we were obliged to get special steel to cut out those rivets, which so convinced me of the advantage of steel for rivets that I cannot conceive why the admiralty are not able to succeed in themselves adopting it. With regard to the dates, I was not aware that Mr. Martell was referring to the dates at which the vessels were built, but there was one vessel we built of steel, I think, about 1860—I have not the exact date in my mind—and she has been running ever since on the Tigris; therefore you would not imagine that there has not been extra care bestowed on the preservation of her hull, but I believe she is still running, and not a single plate in her bottom has shifted since she was sent out there. I think that shows there is no fear of deterioration where good care is taken to begin with. I am told there is a little difficulty found in regard to welding. I have had no experience in welding steel manufactured by this Martin-Siemens process, but an eminent engineer—I do not see him present, therefore I do not give his name—told me the other day he was trying some experiments with it with a view to constructing boilers, and shutting up the boiler instead of riveting it. He said he could not manage to weld the joints together, and therefore he was obliged, instead of following out that method, to come back to the riveted joints. He was desirous to save weight, and was most anxious to have the welded joint. I am afraid Mr. Martell is giving rather too florid a description of the cost. I can only say, not speaking of my own experience but from the opinion of other people as to what the cost is, that I am afraid the increase of cost of a steel ship over an iron ship will be found to be nearly 25 per cent. instead of so small a figure as he puts it. I think I could show Mr. Martell some figures to prove that. I sincerely hope he may be right, because I think nothing tends so much to discourage the use of steel as the cost of it. The only other point which I would mention is this—allusion was made to the government using copper or yellow metal for ship-building. Perhaps it may not be known how very old this is. I believe in the year 1825 or 1826 a vessel was built in the Thames, on the south side, with wooden frames and copper sheets instead of planking for the outside.

Mr. WILLIAM HENRY WHITE (member of Council). May I be permitted to state why in the admiralty practice steel rivets have not been used? When the *Iris* was built the greatest thickness of plates used in her construction were ½-inch steel plates, and having made a series of careful experiments before settling on the fastenings of the bottom plating of that ship it were found that ¾-inch Staffordshire iron rivets placed a very small fraction closer in the pitch than they would have been in iron plates gave ample strength for all the butt fastenings. I was present when those experiments were made. I had to do with the calculations, and I know as a matter of fact that there was no objection to the use of iron rivets in the *Iris* except the necessity for a very few more rivets.

Mr. Benjamin Martell (member of Council). Over what area did you have the plates riveted together?

Mr. W. H. White. Double chain-riveted samples were tested. There was a further reason for the use of Staffordshire iron in that case. A corresponding sample was taken and riveted with Landore rivet steel, which gave splendid results as far as the shearing strength of the rivets was concerned, and also as far as the working. Both samples were taken, and a weight was dropped from a considerable height onto the iron and steel samples. On the whole the iron rivets had rather the best of it, but it was not such a difference as would have been regarded in practice as of very great importance, because the test of dropping this weight was extraordinarily severe, and therefore while I can quite understand that in Mr. Wigram's and in Mr. Samuda's practice steel was used with perfect success, yet I think that it will be easily understood that there was sufficient reason in the *Iris* for not giving up the iron. Nothing would have been gained except the use of a few less rivets. The strength of the skin of the *Iris* is determined by the strength of the weakened sections in the way of the frames, and we could have gained nothing on that except by some special arrangement in framing. As to the rivet tests, Table I shows, as Mr. Martell has said, that if you use iron rivets in the steel plates you must put them a little closer, or must increase their diameter. That is what has been done in the case of the *Iris*. We have also made some trials with a multiple drill in the direction which Mr. Martell sketched out with regard to ship's plates, but there is some difficulty in making the drill with sufficient elasticity in the play for general work. Those are all the points in connection with steel rivets that I need mention.

Mr. William Denny (member of Council). I quite agree with Mr. Wigram in what he has said about Mr. Martell taking a rather *couleur de rose* view of the subject, and I would venture to point out that in the comparison between the ship costing £36,000 built of iron, and the same ship built of steel costing £40,000, Mr. Martell has neglected in his calculation of the current expenses a very material item, and that is the depreciation upon the difference of the cost. It is necessary to consider this, because, as must be well known to most of the members of this Institution, it is a common thing with prudent owners to deduct 10 per cent. per year from the cost of an iron steamer and 7 per cent. from the cost of a sailing ship. If you take the difference between Mr. Martell's two costs, which is £4,500, and depreciate it at the rate at which it would be depreciated for a sailing ship, you have a matter of £315 to be deducted from the £2,220 put down by Mr. Martell. With regard to the tests Mr. Martell has brought before us, I should like him in his reply to tell us whether the iron which was tested against the steel was iron of a superior quality, or whether it was common iron used in common cases by ship-builders; because if it was iron of a superior and very reliable quality, then to a certain extent it puts the steel at a disadvantage. It seems to have been very good iron. My firm, at the beginning of last year, had the opportunity of building a steel paddle-steamer for the Irrawaddy Flotilla Company of Rangoon. The directors of the company up to that time had never built any of their steamers of steel, but entirely of iron, and they were persuaded to build this steamer of steel—so far as the skin-plating and the stringers were concerned—the longitudinal strength was thus entirely of steel, but the transverse framing was of iron. They were not persuaded to do this to get any saving of weight—there was no saving of weight possible, because the scantlings of a steamer built of iron of the same size were reduced as low as they could be before. They built this steamer of steel because they had suffered so severely from many of their steamers being snagged and sunk by trees and stones lying in the bed of the river. This steamer after being built was shipped in pieces to Rangoon. The steel was made to the admiralty tests. and we were curious to know what the result would be on steel plates of being thrown into the hold of a ship, knocked about on the voyage, and taken out at the end of it. We had shipped several iron steamers before, so that there was a good means of comparison. Only last week we received from the manager of the company, in Rangoon, a letter giving a full and most satisfactory account with regard to the steel. and one which every way confirms the good opinion Mr. Martell has formed of it. He said the steel plates arrived without a single mishap. I think this is very satisfactory, because this, although a practical test was a very severe one. These plates went out with their edges punched, and if none of the plates broke in traveling out then I think it speaks very well for steel. In connection with light-draught steamers, you will, perhaps, permit me to say a word on the reason why steel has not come in so largely for their use as at first sight it would appear it might do. The reason is simply this, that in building an iron light-draught steamer the limit to which we have reduced the thickness of the parts is the limit due to the power of the resistance of these parts to buckling. Consequently, when we come to steel, which for all practical purposes over the same space of framing really buckles as easily as iron, we can go no further. In the case I put before you the one inducement to use the steel was its superior quality to resist snagging and breaking. I would not, however, say that there must be an end to the use of steel for light-draught vessels, because if a much more rigid construction, possibly the closer spacing of very small frames, and the use of partial bulkheads and longitudinals were adopted, we might be able to use steel to advantage in river steamers; and I am perfectly convinced that if steel is to be used with any advantage in large ocean steamers, it can only be by the framing being deepened, or the framing being massed in some way or other. So far as the reductions made by Lloyd's are concerned, I believe, with the present construction, they have gone about as far as it is prudent to go; but I think we may go much further if we adopt a construction more suited to the nature of the material.

Mr. A. C. Kirk (member). I think we must all feel very much indebted to a society such as Lloyd's for taking up a new subject in this liberal and scientific spirit, and making certain experiments so that they might have a good foundation for what they do with a material like steel, and, still further, for giving us all the data of these experiments, so that we may judge for ourselves. Allusion has been made to the bad name which steel got in its early days. That material was really steel, but I think that which sells commercially under the name of steel at present is not steel at all—it is simply the highest class of iron. The experiments to which Mr. Martell referred arose from a conversation with one of the gentlemen at the admiralty as to what would be the effect upon our forgings in future, seeing that nobody could tell whether the scrap of which they were made was entirely wrought iron or a mixture of iron and steel. I had two bars made, one composed of a mixture of half ordinary iron scrap and steel scrap, and another of steel scrap. The one composed entirely of steel scrap bent double and seemed as good as one forged from a steel ingot could have been; the one partly iron and partly steel was not quite so good, but better than ordinary iron. I take it from that that the more of this steel there was put in the better iron it was. It has also been said that steel is apt to be irregular in quality. There is no doubt whatever that steel-makers can make it very irregular—they can make it hard and they can make it soft; but in the hands of a good steel-maker I have no hesitation in saying that the material is far more regular than wrought iron, even of first-class qualities. This is what I have found myself in boiler plates, and those of superior qualities, too, when I have tested them: when the test-plate was taken I have had samples cut from one end which failed, but when samples have been taken from the other end very likely they would pass. It is nothing uncommon to find a difference of 10 per cent. between one end of the plate and the other. You seldom find that in a steel plate. There is no doubt whatever, as Mr. Denny said, that Lloyd's have justly weighed the result of the experiments, and that what they are prepared to grant with regard to the ordinary construction of ships is about as much as would be safe. As he remarked, no doubt there is a large field open to ship-builders now to give their attention to other systems of framing and plating, by which the thickness and the stiffness that was originally got from wrought iron for a little money, because the material was cheap, may now be sought after by some different arrangement in the direction of getting depth with a material that is dear. However, these are speculative matters to which I have no doubt the attention of ship-builders will be drawn in future, and therefore I will now let them pass. I think it is a pity—but Mr. Martell is quite aware of it—that in taking the stiffness of strips of plate, the experiments have not been extended to strips of plate fixed at the ends. I think it is so great a pity, that I hope Mr. Martell will have experiments tried in that manner before we hold another meeting, and will give us the full benefit of the result of those experiments. Any one who has seen a piece of steel plate punctured by shot will have seen to what a large extent the tensile strength of steel comes into play in supporting the skin when fixed at the ends; that is to say, after a certain amount of deflection has taken place, it takes a great deal of strength to tear the plate through. I hope Mr. Martell will further carry that subject out. Now, as to testing steel, I am afraid that has been one of the biggest bugbears to its adoption. Manufacturers naturally dislike the testing. It is not the trouble of testing, because I do not think any rational manufacturer would object to that; but it is from the fact that if from a delivery of plates, a test plate or two are taken and cut up, and these have to be replaced, there is a delay very often through that, and the work, especially the piece work which you have arranged, is all upset for want of the missing plates. But if our friends at Lloyd's will allow me to venture to make a suggestion, I think that the right thing would be to throw the *onus* of the quality of the steel on the steel-maker. That the steel-maker, instead of stamping hieroglyphics of various kinds on his plates, should stamp his plates in plain figures, with their tensile strength, it being understood that a certain limit of deviation was to be allowed, say a ton above and below. If that were done, there would then be a representation as to the quality of the steel stamped upon it; and I think our friends at Lloyd's might well employ their time in occasionally checking this maker or that maker, and if they found a maker was in the habit of stamping his plates wrongly, then they would strike him out of their list. I think some such measure as that would prove to be very beneficial.

Mr. E. J. Reed, C. B., F. R. S., M. P. (vice-president). My lord, I only wish to call attention to one important point in connection with this extremely valuable paper. I notice in one instance, which the author of the paper has given, he takes nearly a total reduction of 20 per cent. from the weight of the iron ship in taking the weight of the steel ship. He takes 1,090 tons as the weight of the iron ship, and 890 tons as the weight of a steel ship of equal power, and the difference is only 18 tons less than the 20 per cent. He only allows the steel ship 18 tons more than the 20 per cent. of the iron ship. If we can do that, then we have made very much greater progress in this matter than I was prepared to believe. I myself have given a good deal of time lately to the designing of steel ships from a commercial point of view, to see how far steel could be adopled for commercial steamers, and I was met by this great difficulty, that although Lloyd's are willing to allow 20 per cent. off the weight of iron in fixing our steel scantlings, that, practically, when you come to design a ship and fix the scantlings of the vessel you cannot take off anything like 20 per cent., and you will see the reason: if you start with a standard and accepted thickness, that you can purchase, but if you take 20 per cent. off that, you frequently have a thickness which you cannot get—you get to minute fractional differences of thickness which you cannot roll to, or at present cannot. What I found was that practically speaking when you take the trouble to go through the whole scantlings of the vessel, and to take the 20 per cent. off which Lloyd's circular allows, you bring the 20 per cent. down to 13 or 14 per cent., and I could not get beyond that point. That being the case, I confess in some instances I was unable to adopt steel when I had many inducements to do so, and should have been delighted to do so, and for no other reason than that. When I find so high an authority as Mr. Martell giving us illustrations in which nearly 20 per cent. is saved, I begin to think I must have neglected some considerations that he has attended to, but I can only say for myself as one anxiously interested in this matter and desirous to see it making the progress which this paper of Mr. Martell's will enormously encourage, that I should be very glad if he in his reply could show how it is that when you come to take 20 per cent. off all the scantlings of an iron ship you can adhere to the thickness which you can obtain in the market and can get rolled. I think you will see all the importance of that point.

Mr. William John (member of Council). I should like to make one or two remarks with reference to what has fallen from Mr. Reed, and I can speak to this from experience, because at Lloyd's Register we have found the difficulty to which he alludes arising in this way. When a steel ship is submitted for classification with the scantlings marked upon the drawing, and a reduction of 20 per cent. is aimed at, it is easy to see that one of two things must happen. If you have ten-sixteenths plating you can take off 20 per cent. as easily as possible by taking off two-sixteenths, but if you are taking 20 per cent. off nine-sixteenths you get into an unworkable size and number, and the consequence is you must either go a little above or a little below. If you go a little above the 20 per cent. on each item, you would find when you got right through the section you had a total of 25 or 30 per cent. reduction. If, on the other hand, you give a little on the other side you may reduce it down to 13 or 14 per cent., as Reed has very properly said. A point to which we give great attention is this, to try by every means in our power where there is a little put on in one direction, in the framing, say, to allow a little off the reverse frame, or where there are different thicknesses of plating, if a little more than 20 per cent. is taken off one strake of plating, to have a little less on the next, so as to get as nearly as possible to a general reduction of 20 per cent. I think I can say in several cases the builders themselves have admitted that going over the whole section we have got quite up to 18 per cent. All I can say is that Mr. Martell and the committee at Lloyd's, I am quite sure, would desire to meet builders in their attempt wherever there is a fair way of compensating one thing for another to bring it as near a general reduction of 20 per cent. as possible. If you cannot allow something in the top, perhaps you may for an addition in the bottom, and it is right in making this compensation that you should keep as near to the several parts of a ship or the neighborhood of them as possible, so as to get a proper equivalent for the rules. There is another point which I will mention, and it is with reference to the riveting. It is quite true that in steel ships, and in more than one instance as we have heard it at these meetings, steel rivets have been used, and used successfully, and that is a very important fact to remember; but if we find steel rivets used in a ship, and they fail, I would point out this, that twenty successful instances of steel rivets being used in a steel ship would not outweigh one instance where the rivets turned out untrustworthy. It is for reasons of that kind that the Admiralty and the Committee of Lloyd's while not wishing to discourage the use of steel rivets, wish to be as cautious in the matter as possible until they have got to the bottom of the amount of danger that arises from overheating and the special dangers that might be due, or might hereafter be shown to arise from steel rivets. Mr. Kirk has mentioned the question of the rigidity tests. No one can regret more than we do at Lloyd's that we have not a more complete series of rigidity tests, and that we have not had a series of tests with the ends fixed as well as with the ends supported. I admit that there might be differences arising from experiments where they are fixed in the one case and where they are merely supported in the other, but in all these experiments it is a matter of time—it is a matter of cost—and I can only hope that Mr. Kirk himself and many other private ship-builders will not only look to us for experiments of that kind, but will make experiments for themselves and will give us the results of such experiments. If they do I am sure they will be very valuable and will be appreciated very highly.

Mr. John MacFarlane Gray (member). My lord, perhaps it is hardly worth while to make this remark, but since Mr. John seems to have some doubts with regard to steel rivets, I think some valuable information might be gained by communicating with Messrs. Park & Brother, of Pittsburgh, who made some experiments some years ago on a steel boiler. This boiler was 40 inches diameter and 8 feet long, shell ¼-inch bare, and in the testing the boiler bellied, and became 3½ inches greater in circumference in the middle of its length, and the failure of the boiler was at a place where they had run short of steel rivets and had put in six iron rivets. The experiment was stopped at 790 pounds pressure per square inch, the pumps being not large enough to make up for the leaking.

Mr. C. H. Wigram. A remark has been made as to the difficulty of reducing 20 per cent. of iron in specified ways. I have a paper in my pocket which I should like to hand in to show how simple it is.*

Iron, thick.		Equals—	Steel, thick.
Eighth of inches.	Sixteenth of inches.		
	$\frac{15}{16}$	.937—20 per cent	.75 = $\frac{12}{16}$
$\frac{7}{8}$	$\frac{14}{16}$	.875—20 per cent	.70 = $\frac{11}{16}$
	$\frac{13}{16}$	.812	.65 = $\frac{10}{16}$
$\frac{3}{4}$	$\frac{12}{16}$	.75	.60 = $\frac{10}{16}$
	$\frac{11}{16}$	.687	.55 = $\frac{9}{16}$
$\frac{5}{8}$	$\frac{10}{16}$	.625	.50 = $\frac{8}{16}$
	$\frac{9}{16}$	.562	.45 = $\frac{7}{16}$
$\frac{1}{2}$	$\frac{8}{16}$		.4 = $\frac{7}{16}$
	$\frac{7}{16}$	.437	.35 = $\frac{6}{16}$
$\frac{3}{8}$	$\frac{6}{16}$	.375	.3

Sir R. Spencer Robinson, K. C. B., F. R. S., admiral (vice-president). My lord, I only wish to say two or three words, because I think the practical part of the question can be dealt with very easily and in very general terms, and does not, perhaps, require so much detail and so many minute observations as have been laid before us to-day. There is no doubt that the practical details and minute observations made by various members of this Institution are of very considerable value, and will and must be taken into consideration in working out the great scheme, for it is a great scheme, of substituting steel with enormous increased power over the best qualities of iron that can be got. What I wanted to say, and what occurred to me while listening to the very interesting discussion that we have just had, is that those details are not necessarily objections to the permanent and positive substitution of steel for iron. They are matters of detail and matters of manufacture, and there are so few institutions in this country, as I am told, who have yet gone thoroughly into the subject of manufacturing steel instead of iron, that the observations that have been made, the difficulties that have been suggested by my friend, Mr. Reed, and others, may possibly and I think will certainly in process of time be overcome, and these legitimate objections for the moment to the difficulty of reducing the scantlings, and of obtaining a given percentage off the weight of a ship, will disappear as we proceed further in the knowledge of the manufacture of steel, and as more institutions enter upon the investigation of this point than are at present employed upon it. I can only therefore say that, both from the objectors to, and also from the advocates of the use of steel, you will see the enormous increase of power we shall gain by the use of steel amounting to a good deal more than that referred to in Lloyd's rules. There seems generally to be an impression that 25 per cent. at least is

* The following is the table handed in by Mr. Wigram.—Ed.

due to the additional strength of steel over iron. That being the case, all I wish is, as far as I can do so by the application of legitimate reasoning, to show that there is every reason in the world for encouraging all those who are connected with the production of ships to use steel, and not to be afraid of the temporary difficulties that its use may offer, but to proceed boldly and firmly in the course pointed out, and I have no doubt in the world that enormous success will attend the development of it.

Mr. HENRY HARTLEY WEST (member). I am sure we must all be very much obliged to Mr. Martell for putting this matter before us and giving us such valuable tables. In reference to some of the tests which have been applied, I should like to have asked a number of questions, but our time being limited I will pass from that and draw attention to one point which seems to me to be of considerable importance. That is a matter which Mr. Kirk brought before us at the autumn meeting last year, that in some tests of riveted work that he had made he found that the seat of the rivet in the plate yielded under the strain, crushing up, as it were, the plate behind the rivet. To meet that, probably the best course to adopt would be to increase the rivet area, not by increasing the diameter, but by increasing the number of rivets; for, since the surface under crushing strain only increases in the direct ratio of the diameter of the rivet while the rivet area increases as the square of the diameter, the increase in the number of rivets would bring out a better ratio between the area of plate under crushing and the area of rivets under shearing strains, than a corresponding increase in their size would accomplish. The quality of the material is such that I think all of us must receive it with very great satisfaction; and when it is accompanied, as it is in some cases put before us for classification in the underwriters' registry, with special arrangements of material and construction it is open to reductions which could not be allowed in the case of ships built in the ordinary way. This matter is one which I dare say Mr. Denny will bring before us in his paper this evening—I hope so at any rate. In reference to a remark of Mr. Reed's, made this morning, that you cannot make a reduction of any given percentage because you are stuck fast with your 16th, I hope to show you this evening that it is quite possible to do so.

Dr. CHARLES W. SIEMENS (associate). With reference to the observation that fell from Mr. Reed, as to the difficulty of rolling steel plates to dimensions that would present a reduction of weight equal to 20 per cent., I would mention that when the material for the *Iris* and the *Mercury* were ordered from the Landore Company a wish was expressed by the authorities that the weights of the plates should in no case exceed those specified, but that it would be desirable to make those plates perhaps 2 per cent. less in weight than would follow from the calculation. I believe the Landore Company acted strictly up to that, and that the total weight of the material supplied was just 2 per cent. below that calculated, showing that there really is no difficulty in working by weight instead of dimensions. I would suggest that it would be a far more rational thing to order the plates by weight per square foot, rather than by vulgar fractions of an inch thickness. With regard to riveting, I for one would strongly advocate steel rivets in preference to iron. It is true that at Pembroke the experiments tend rather to show that no material advantage would be gained by the employment of steel rivets, but at that time the question was hardly sufficiently understood. Now, steel has been produced which I think answers its purpose perfectly, and reduces the risk of rivet heads falling off to a minimum. I may mention that at another institution Mr. Boyd, the engineer of the Slipway Company, will read a paper to-day giving the result of the construction of several steel boilers in which steel rivets were employed, and he states in that paper that not a single rivet gave way or gave any trouble whatever in the manipulation, showing clearly that with a little care difficulties that have been complained of—such as overheating—may be overcome. The advantage of steel riveting over iron is not only in the rivet itself, but it is in a great measure in the plate which has to be cut away to a much less extent, and thus leaves a larger net area of metal to resist the strain. Then again, if the rivets are put the same distance apart as they would be put in an iron plate 20 per cent. thicker, it is natural that these rivets stand too far apart for this reduced thickness of the plate, and this throws a buckling strain on the plate. I would suggest that in riveting steel plates together, the distance between rivet and rivet should be the same as that which would be adopted if a thin iron plate were used—in fact the reduction should be proportionate—the moment you use one material for the plate and another material for stitching the plate together, there is a disproportion between the two elements introduced which naturally must tend to weaken the whole. Perhaps I may be allowed to say one word before I sit down with regard to corrosion. Certain laboratory experiments that have been tried seem to show that steel corrodes faster than iron, whereas most of the working results that have come to my knowledge seem to show the contrary, and to prove that steel wears longer. We have heard to-day of steel ships, from Mr. Martell himself, that have stood wear and tear exceedingly well. But I have no doubt that some steel may be introduced which is liable to corrode at a greater rate than iron would; and although I perhaps have no right to speak absolutely and definitely on the subject, I believe it is the result of an excess of manganese in that steel, and it would perhaps be well for steel users to turn their attention to that subject. Manganese is an exceedingly convenient agent in order to give to steel, or homogeneous iron, the high degree of ductility which is desirable, but it is by no means a necessary element, because at least the same ductility and the same strength may be obtained without an appreciable percentage of manganese in the material; and my experience, which is somewhat limited as to the wearing quality and resistance to corrosion of the two materials, goes distinctly to prove that with an increase of manganese beyond a very narrow limit the steel becomes more corrosive, does not weld with the same facility, and is not so absolutely uniform as when a little manganese is used.

The PRESIDENT. I shall not presume to add anything in the way of opinion on either side to the very interesting discussion which we have had. I only wish to explain that I thought it my duty, in consequence of the very important and practical character of this paper, not to limit the discussion strictly within the limits we have laid down, but I cannot call on Mr. Martell to offer any remarks he may wish to make in reply, without, in the name of this meeting, thanking him for this very valuable contribution to our proceedings.

Mr. B. BARTELL (member of Council). My lord, since so much time has been occupied in this discussion I will endeavor to make my remarks as short as possible, and I think it better to confine myself to the principal points put forward, and to discuss them more prominently than the others. Now, first, with reference to the rivets: No doubt, as Dr. Siemens has said, when you are using steel rivets it becomes necessary to look at them differently from iron, and to endeavor to apportion them in a suitable manner, both as to their diameter and as to the spacing of them. If I remember rightly, Dr. Siemens promised us to make some experiments on that subject, and I hope he will see his way to do so. Then further than that, as to the constituents of the material, if information could be ascertained with reference to the best proportion of manganese it would be most useful. I can only say with regard to the steel rivets that were found not to answer quite so well as could be wished, they were rivets made from steel from the Landore Company, and I shall be happy to give Dr. Siemens a little of that steel in order that he may analyze it, and then perhaps he may be able to ascertain how it was they did not turn out so satisfactorily as the other rivets which were used.

Dr. SIEMENS. The same steel was used at the Slipway Company.

Mr. MARTELL. I have stated only what was told me. Perhaps from analysis Dr. Siemens could give us some useful information on the point. I regret that Mr. Laird has not given us the benefit of his experience, because it is very great, on the subject of riveting, as it is a matter of so much importance on this question. Two ships were built by Mr. Laird which turned out very satisfactorily in every way, and I am sure that a few words from him would be of a great deal of service. Perhaps his lordship would even now allow it.

The PRESIDENT. I am well aware of the value of Mr. Laird's opinion, but I am afraid that any addition to the discussion now will scarcely be regular, but as it is the wish of the meeting that Mr. Laird should say a few words, I can offer no objection.

Mr. HENRY HYNDMAN LAIRD (member of Council). I wish to state with reference to Mr. Martell's paper and the discussion which has taken place, that my firm have within the last year built two steamers of steel, one of steel made by the Bessemer process and the other by the Siemens-Martin process, and in both cases they were riveted entirely with steel rivets. We had no trouble whatever with the riveting. In the larger vessel of about 1,000 tons we took very great care in watching the riveting during the time the work was going on, and had very severe tests made, and I do not think we had one instance of a rivet-head flying. In arranging the riveting we adopted the plan that Dr. Siemens stated he thought would be the best, namely, we reduced the diameter of the rivets in proportion to the thickness of the plates, and made the spacing of the holes the same proportion to their diameter as it would be in iron. The only difference made was that we left a slightly greater lap between the edge of the holes and the edge of the plate, because we thought, from experiments, that would to a certain extent remove any danger from loss of strength arising from the punching of the plates. With regard to the reduction of the scantlings, I may say that we went nearly as far as 25 per cent. and did not find any practical difficulty in getting the thicknesses we wanted, because we ordered all the plates by weight, giving the weight per superficial foot, and the makers had no difficulty in carrying out our orders. Both these vessels are fitted with machinery of exceptionally high power in proportion to their displacement, and of high speed, and so far we have had the most satisfactory reports of their performance in every way. I can only say that our experiments confirm all the most favorable views taken of the use of steel, and that we feel it must be adopted much more generally than it has been, particularly now that it is regular in quality and can be depended on.

Mr. Martell. With reference to Mr. Laird's remarks about taking the weight of iron per foot, there is no doubt that is a practical way of getting at it under some circumstances; but there is this difficulty attending its general adoption, that if you have your vessel inspected by surveyors, and it is wished to know what scantlings are put in the ship, you can ascertain the thickness by the report of the surveyor, because he can take the measurements for himself; but no surveyor can tell by looking at a plate what is the weight of it, and you cannot have it got out to weigh it. That is the difficulty found in taking it by weight. But I may say this, that if the present gradations are found to present great difficulty, we can meet it in this way. We have, for instance, the scantlings of Lloyd's Register translated into three continental languages. Where they use the metrical system we have all those tables in the metrical form, and it is just possible that these subdivisions may be made in that manner. Instead of taking the divisions which we limit ourselves to in iron, viz, of the 16ths of an inch, we have gone down in steel to the 32ds of an inch. I do not think we should draw these lines too finely, because if we do make these very fine divisions, it is found perfectly impossible for surveyors, without a magnifying glass, to go and take the sizes. Still the required reductions for steel can at the present time be made very nearly. We have found no difficulty in coming within 18 or 18½ per cent. The builders themselves have gone very carefully into it, and after making these deductions, we find that the reduction will come to about 18 or 18½ per cent. I dare say what Mr. Reed referred to took place when we did not adopt that 32d-inch division, which has enabled us to do more than we did before. With regard to riveting, those of experience who have tried it maintain that perfect riveting can be done with steel rivets if you only heat them so as to insure their being heated uniformly at a proper temperature. The only difficulty is where they are heated in an open furnace by careless boys. Mr. Laird himself went round and tested these rivets in place—he did not take especial care, it would appear, to see them riveted—whereas Messrs. Thomson tell me they placed rivets of steel and iron in the hands of their boys to heat, without telling them what they were; that they tried a large number, and in no instance did they find any danger arose from overheating. That is a great practical test of the efficiency to which steel rivets can be brought. The only difficulty that has arisen is whether you can rely on these boys heating the rivets sufficiently, so as not to have too many of them burnt. Messrs. Thomson say they found they are more likely to burn iron than steel. Then Mr. Denny asked with regard to the quality of the iron. This was ordinary ship iron used in making these tests. With reference to Mr. Samuda's remark, the ship of 1,200 tons was built of Bessemer steel, and the plates were, I understand, carefully selected. Then with regard to the cost, which I think was referred to by Mr. Wigram, I can only say that what I stated was the actual cost. If he wishes a ship of this kind built, I can place him in the hands of a firm who will be glad to build him a ship at that price this moment. Then Mr. Kirk made a remark with regard to throwing the responsibility on the manufacturers of steel. I can only say that Lloyd's Register Society have done that to this extent, that in their circular they say, Here is a mark you must have on every plate and angle-iron before we will accept it for vessels to be classed in our register, and the mark that is placed upon it must denote that the materials will stand the tensile strain of from 27 to 31 tons; that every piece and every plate has gone through a temper test showing that if plunged at red heat into water at 82° F. you can afterwards bend it double. That is a test that makes the steel manufacturer responsible, and if you find in using this steel it does not stand that, it is only for the shipbuilder to call on the manufacturer and say, How is this? And we know, from what we saw in going round to all the manufactories, that there is a specimen kept of every plate and angle, and the number of it, and on comparison they would be able to tell us the cause and to rectify the mistake. That guarantee, in my opinion, is far better than Lloyd's Register taking on themselves the responsibility of steel manufacturers. I have to express my thanks for the kindness with which this paper has been received, and I hope it may lead to other more useful experiments being made.

ON STEEL IN THE SHIP-BUILDING YARD.

By WILLIAM DENNY, Esq., *member of Council.*

[Read at the twenty-first session of the Institution of Naval Architects, March 19, 1880; the Right Hon. LORD HAMPTON, G.C.B., D.C. L., president, in the chair.]

I purpose, in the following paper, to state as shortly as possible some of the experience my firm have had in the use of mild steel during the last two years.

We first used steel during the blockade-running period, and introduced it into some portions of paddle steamers we built for blockade-running purposes. The material as then made was far from satisfactory, and its behavior did not encourage us to extend its use.

In 1876 we made our first acquaintance with the mild steel now in use, when we built for the Irrawaddy Flotilla Company a light-draught paddle steamer called the *Taeping*. All the skin and stringer plates of this vessel were of Bessemer steel, the rivets being of iron. We had perfect satisfaction in the workings of this material, and the steamer, after being put together in Rangoon, fully evidenced the value of steel for vessels of her type. On one of her earliest trips she struck on a snag in the Upper Irrawaddy, but came off safe and sound, her plating heavily indented but unbroken. We were informed by the superintendent engineer of the company, he was of opinion that if she had been of iron she would have gone down under the circumstances.

Since the building of the *Taeping* we have gone largely into the use of steel, and at present have little else in our yard. This paper covers the period following our building the *Taeping*, and the steel now referred to is entirely of the Siemens-Martin description. We did not select this kind of steel, or specify it, but fell into the use of it from the fact that it was most frequently offered us, and that most of the steel works employed in producing ship-building material work upon this principle. All the sea-going steamers we have launched till now *have been* built of steel produced by the Steel Company of Scotland, while the steel for the light-draught steamers was made by the Steel Company, the Landore Company, and the Butterley Company.

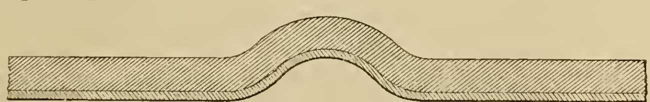
Of the steel supplied to us we have had very little reason to complain, indeed our only real ground of complaint has been the uncertainty of its delivery—a fault arising probably from the newness of the works, but none the less vexatious and serious. Unless the various steel works improve in this particular they will seriously damage their own prospects, and a word of warning upon the point may not be amiss to them. In our latest contracts we have returned to iron for no other reason than our dread of seeing our yard disorganized through the bad deliveries of material. The method of testing adopted by Lloyd's has also greatly aggravated the effects of the bad deliveries, and will be referred to further on.

Regarding the behavior of the steel in working, I cannot do better than quote from a letters we addressed to Mr. Waymouth on the 28th of last month, in reply to an inquiry made by him on behalf of Lloyd's committee for information upon this subject. In this my firm said:

With reference to the failures in manipulation, we have very few cases to report, although we have kept a note of them. We divide these failures into failures of plates and failures of bars. The first failures of plates we noticed were in the case of four of the flanged plates forming the bilge-keels of No. 224. These four plates, after they were screwed up, developed small cracks through some of the rivet holes, piercing the flanges attaching the plates to the ship's bilge. We discovered that these cracks were due to our workmen having finished the plates at a black heat. We removed them, cut out the defective portions, welded in fresh pieces, annealed the plates as a whole and replaced them. In No. 226, which had a plate keel, the aftermost length, which was bent to the form of the heel of the stern frame, developed a small split in the extreme end. The length of plate permitted the split portion to be cut off. The plate otherwise was found perfectly good, and was used in the steamer. One of the flat keel plates of this steamer, after being finished, was heated to a cherry red and laid down for cooling; while cooling it bent up in the middle, and was hammered down from the top side. On being examined, a fracture was found on the under side about 6″ from the end, and the plate was rejected. These are all the failures we have to report in our working of steel plates, and without exception they can, as you will notice, be readily traced to the working of the material at a black heat.

This is the really unsafe thing to do with steel, and our foremen and men have now received instructions that it is not to be attempted, and that if a piece cannot be finished at a red heat it must be completely reheated or finished cold.

In bars we have to report no failures in the working of either the ordinary bulbs or the Butterley sections, and the welded knees on the beams have in no case shown any defect, which they might have been expected to do, if at all, in being riveted to the frames. In angles we have had one boss frame which cracked on the deep flange at the outermost portion of the boss shape. This was evidently due to the workmen laying this flange down at a black heat. In our light-draught work, where we have short pieces of angle shaped thus—



to form doubling pieces over the limber holes—we have had one or two cases of the outer edge of the flange tearing slightly while being cressed at a red heat, but no case of breaking.

We think that, considering the failures above noted are all that we have to report out of a consumption of about 7,000 tons of steel, they are very far from being of serious moment. We can point to no similar experience in the use of iron; indeed, in a small steamer we are now building of that material, we have had to reject for failure, under manipulation, more plates than the total number of failures now reported to you. We may remark that the 6 by 3 inch frames, which we are working in steel for Nos. 237, 238, and 239, have not as yet produced a single failure or crack. Iron frames of similar dimensions in a steamer we built some years ago, manufactured by one of the best Scotch makers, gave us a very considerable amount of trouble from cracking on the inner edge of the deep flange in riveting them round the bilge. We believe, if a careful record were kept of the behavior of ordinary ship-building iron, under manipulation, as compared with the behavior of steel under manipulation, many people would be surprised to find the tables completely turned in the matter of unreliability, and that enormously to the disadvantage of iron. We had the pleasure of bringing under your notice, some time ago, a good illustration of this in the behavior of the pieces of our light-draught steamers under shipment, comparing those built of iron with those built of steel.

The letter referred to in the last part of the foregoing quotation described the behavior under shipment of the pieces of light-draught steamers built of steel, as compared with that of pieces of similar steamers built of iron. We had before 1878 built a considerable number of these vessels in iron. They were put together in the yard and then shipped to Glasgow in lighters, from which they were transhipped on board steamers going to the East. During this shipment and transhipment we were invariably annoyed more or less by corners of plates coming off, angle irons cracking, floors breaking, and such little mishaps. Last year we built and shipped six steel paddle steamers of various sizes, varying from 250 feet to 80 feet long, without losing anything by breakages. These vessels were entirely of steel and steel riveted, and I think that, as a rough practical test, nothing can more effectively prove the general reliability of steel as compared with the unreliability of iron than this. Indeed our whole experience leads us to reverse the ideas largely held regarding steel and iron, and to look with confidence on the steel and doubt on the iron. Our foremen and workmen hold this view of the matter very strongly, and speak most contemptuously of going back to iron. Their confidence in the power of steel to do everything and stand everything, excepting working at a black heat, is of the firmest nature, and it will be acknowledged such confidence cannot be causeless.

In addition to the regular testing carried out by us for Lloyd's, and also for the light-draught work we generally have in hand, we have made some experimental tests, a few of which I wish to bring under your notice, and in doing so I must acknowledge the very considerable assistance and valuable advice afforded us by Mr. William John, also the readiness with which Mr. Mumford, our local Lloyd's surveyor, entered into these experiments, and the desire shown by him to take interest and give assistance in all test experiments, even over and above his regular duties.

Among the earliest experiments made by us, was a series of tests intended to find out whether rapidity in breaking the pieces under tensile strain affected their results disadvantageously. The inquiry was forced upon us by objections taken to rapid testing, and its results very much surprised us. They are shown in Tables I and II. The time was taken by a chronograph started whenever the lever of the testing machine floated and stopped when the piece broke. Table I shows the results afforded by a plate of a hard nature. From this plate twelve test pieces were prepared in the usual way, one-half of them being tested as rapidly as possible, and the other half slowly. You will notice that the first series, broken in an average time of a minute and a half, show an average of 40.63 tons of tensile strength, and 11.96 per cent. extension. The second series, broken in an average time of eleven minutes fifty seconds, show a mean tensile strength of 39.86 tons and 11.48 per cent. of extension. The difference is hardly worthy of mention.

In Table II a similar set of experiments are shown carried out on a mild plate, and at three different rates of speed. Practically no difference is shown in the results. Both sets of experiments hint at a slightly less extension tested slowly than quickly. In the first series of the first set, Nos. 3 and 4 are peculiarly noteworthy as being broken under a minute. Yet the mean of their percentages of extension is little affected, and the lowest is no lower than No. 4 of the second series, broken in ten minutes fifty seconds. In considering this it is worthy of remark that, to break the pieces in less than a minute, the hydraulic pump had to be worked full swing, throwing shock after shock on the machine, as was made evident by the violent vibrations of the test lever. From these results, I think, it may be assumed the time element, unless widely extended, is of little effect in the practical testing of steel.

Another set of experiments is shown in Tables III, IV, and V, and refer to the effects of simple annealing. Eight test pieces were cut from each of two quarter-inch plates, one known to be hard and one known to be very soft. After being prepared in the usual way, one-half of each set of pieces was carefully annealed. In the hard plate we have a mean tensile strength unannealed of 32.97 tons, and a mean percentage of extension of 16.65. The annealing reduced the mean tensile strength to 28.52 tons, or by 13.5 per cent., and raised the percentage of extension from 16.65 per cent. to 24.12 per cent., or by 45 per cent. The soft plate showed unannealed 26.6 tons mean tensile strength, and 24.32 per cent. mean extension. Annealing lowered the tensile strength to 24.05 tons, or by 9.6 per cent., and raised the extension to 29.87 per cent—22.8 per cent. of a rise. It is curious that the hard plate, although decreased in strength and increased in extension by annealing, showed no improvement in the bending test due to annealing.

A similar set of experiments is shown carried out in Table V, upon a ½-inch plate of mild nature. The decrease in tensile strength shown here is not more than 5.6 per cent., and the increase in percentage of extension does not exceed 7.3 per cent., the annealing being evidently less powerful for change in thick than in thin plates. However, this may be, there are apparently two lessons to be learnt from the foregoing experiments, and these are, that hard plates may be brought within desired limits of strength by simple annealing, and that soft plates may be injuriously reduced by the process. This latter is a matter of serious moment, especially when we are, as now, dealing with steel of light tensile strength. If plates of 29 tons average strength are to be annealed, and thereby reduced to 26 tons, it is evident we shall end in working with a material in many parts of a ship of less strength than assumed in our calculations. On this account my firm have preferred the practice of rimelling punched holes, where such was required, to annealing the plates. The rimelling removes any bad effects of punching, and without lowering the general strength of the plate, which the annealing unquestionably does.

In connection with this matter of annealing, there very early arose a point with regard to the beam-knees of the steamers we were building, as to whether we should not anneal after finishing them. These beam-knees are split and welded in several heats, and Lloyd's authorities expressed some doubt as to whether it would be prudent to pass them without annealing as a whole. For a considerable time, therefore, we were in the habit of annealing the beam ends, but latterly we have not done so, and have had no cause to regret the change. Before making it we carried out a series of experiments on welded beam-knees, both of the common bulb and Butterley sections. Some were annealed entirely, some annealed in the knees only, and some unannealed. They were all subjected to a similar and very rough treatment, the knees being bent round flat on the beam, and the end of the knee doubled in upon it. No difference could be discovered between the behavior of the different specimens; if anything, the completely unannealed beams having rather the best of it.

In Mr. Martell's paper on "steel for ship building," he mentioned some successful attempts made by Mr. A. C. Kirk to shingle the scrap of mild steel into forgings. Mr. Kirk has, I believe, since that time continued to push this matter, and with considerable success. Following him, we have gone largely in for scrap-steel forgings. Our practice commenced by making the stems of all the sea-going steel steamers we built of scrap steel. At the same time we made the stems, stern-posts, and rudders of all our light-draught steamers of the same material; and as success followed each fresh attempt we pushed further on, till now all three of the sea-going steel steamers we have on the stocks are to have all their forgings, stems, stern-frames, and rudders of the same material. We have now in place one of these stern-frames weighing 9 tons. Before, however, going this length, we thought it prudent to carry out some experiments upon the material, comparing it with ordinary iron scrap forgings. The results are before you in Tables VI and VII. For the purposes of comparison, two blooms were forged out of common scrap iron, and two out of scrap steel, and both worked down under the hammer into flat slabs resembling plates about $\frac{3}{4}$ inch thick. From each of these three pieces were cut for tensile tests and two for deflection tests. You will notice that in the tensile tests the scrap steel shows a mean tensile strength of 23.8 tons, and a mean extension of 19.5 per cent. against 20.6 tons, and 14.9 per cent. of extension in the iron plates—a decided gain, though not so decided as the difference between an original steel and iron plate. The individual tests also agree better together in the steel than in the iron scrap forgings. Under deflection we have, at 5,000 pounds strain, the iron with a mean deflection of fully 50 per cent. more than the steel, and at 8,000 pounds with about one-third more. These results point to the very considerable superiority of forgings made from steel scrap over those made from iron scrap. Our forge people report no failures in the manipulation of the scrap steel. The men complain that it is tougher to work, but beyond this we have no complaint, and we have not as yet had to reject any of the forgings, or to find fault with them. A steamer we lately built for New Zealand, having engines of 1,600 indicated horse-power, had both piston-rods of scrap-steel. They worked most satisfactorily, and the ship is now running on her regular service.

Last year my partner, Mr. Brock, had occasion to have some experiments on riveted joints made by Mr. Kirkaldy. These joints were formed of steel plates and riveted with steel rivets. In four cases complete shearing of the rivets took place, and these cases showed successively 19.4, 20.6, 19.2, and 19.8 tons shearing strength per square inch of rivet area, or a mean of roughly 20 tons. As the rivet bars from which these rivets were made had a tensile strength of 28.9 tons per square inch, this result not only astonished, but rather disquieted us, and led us in *our* ship work to treble rivet all our skin butts in the steel ships we were building for half the length amidships, completing all the rows, so as to bring the strength of rivet area up to the strength of the most heavily punched part of the plate. The result was certainly widely divergent from that assumed to occur in iron, where the shearing and tensile strength per square inch of area are supposed to be identical. We therefore commenced a double set of experiments, all with drilled rivet holes, and included in them, besides the comparison of iron and steel rivets, a further comparison as between hydraulic and hand riveting, and as between scrap and homogeneous steel rivets. We also added to these a set of experiments on the effect of taking the sharp corner off the cutting edges of the rivet holes, to see whether this expedient would increase the shearing strength of the rivets. The results are shown in Tables VIII and IX, and a combination of the two sets of tests in Table X. Regarding these, it may be remarked that the hand riveting shows much less regularity than the hydraulic, and is, on the whole, inferior to it. If we judge purely by the hydraulic riveting, we may assume that the scrap-steel rivets have about 21 per cent. more shearing strength than iron rivets, and that the homogeneous steel rivets have about 5½ per cent. more shearing strength than the scrap-steel rivets. The difference between the scrap and homogeneous steel is slight. Between the scrap-steel rivets and the iron ones 21 per cent. of a difference should, however, be sufficient to recommend the former, or rivets of homogeneous steel. If any action of a galvanic nature is set up between the steel plates and iron rivets, as has been suspected, a further reason for preference may be advanced. It may be asked why the steel rivets in Mr. Kirkaldy's tests sheared at a mean of nearly 20 tons per square inch, and those in the experiments now described at, say, 24½ tons. In the rivets tested by Mr. Kirkaldy the diameter was 1.13 inches, while in the rivets tested by us the diameter was .82 inch, and it is possible the smaller size of rivet may, area for area, be better able to resist a shearing strain. It is also possible that shearing a single rivet may show more favorably than shearing a number. The blunting of the edges of the holes seems to have brought the hydraulic riveting up from 23.3 to 24.3 tons, and the hand riveting from 21.6 to 24.3 tons shearing strain. Taking a fair view of the matter, I do not think it would be prudent to assume in ship riveting—which must in the most important part, the skin, be done by hand—a higher shearing strain than 22 tons per square inch of area against, say, 19 tons for an iron rivet. Granting this, it would seem that a full reconsideration of the subject of riveting in steel is called for; and we should recognize that the same rules can hardly apply to a material which has a shearing strength of 22 tons against a tensile strength of 29 tons, as apply to a material having the one 19 and the other 20 tons. We shall require proportionately more riveting in steel than in iron, and in the butts especially. For half the length amidships, I think, in any steel steamer of over 300 feet long, treble-chain riveted butts would be a prudent precaution from bilge to gunwale. Such riveting would also have a strong tendency to steady the butts of such thin material against local panting. The butt straps also should be made considerably thicker than the plates on this account.

One of the most important points in connection with steel is to get at some idea of the mean strength and elongation obtained in it, under a given set of test conditions. To illustrate this there are shown in Table XI the mean breaking strains of angles and bulbs and plates, separately, as deduced from all the tests made (excluding rejections) for the four sea-going steamers we have built of steel to Lloyd's class. There is also shown the mean percentages of extension for each. Lloyd's conditions are that the tensile strength must not fall below 27 tons, nor exceed 31 tons per square inch, and that the percentage of extension on 8 inches must not fall below 20 per cent. The mean of Lloyd's limits of tensile strength is 29 tons, and, if you will look on the tables before you, you will find only one instance in which the mean tensile strength of the plates falls below this, and only slightly. The angles and bulbs fall below the mean in two out of the four ships. The extensions are wonderfully even and good. Taking the mean tensile strength all over it stands at about 29.12 tons, with a mean extension of 22.65 per cent. As a result in attempting to meet a given set of conditions, and to meet them at the same time safely and well, I think this worthy of a ready commendation; and the steel company of Scotland, the makers of all the steel used in these four steamers, certainly deserves credit for its success.

Looked at, however, from a constructor's point of view I am not so contented with the result. It would be rash to assume as a factor in our calculations for strains, from the results now laid before you, a higher tensile strength than 28 tons per square inch, and we must always remember that the annealed plates will probably drop from 2 to 2½ tons lower. In the face of this contingency I think Lloyd's have been only prudent in restricting the reduction of scantlings to an overhead of 20 per cent.

But is it necessary we should restrict ourselves to such very mild steel? I think not. Till very lately my firm did so, but our last contract for steel for a large light-draught steamer had limits of tensile strength from 29 to 33 tons, and we only required an extension on 8 inches of 18 per cent. This increased strength in the steel will greatly help the rigidity of the steamer, and will not, I believe, be accompanied by any troublesome consequences.

I believe it has been too readily assumed that steel of high tensile strength is unsuitable for ship-building. Anyway, unless we can work it we shall never reap the full benefit steel can confer. Would it not be possible, perhaps, while making the shell plates of a softer material as being more liable to collision, to make all the inner plating and framing of a harder and more rigid steel? Something might in any case be done in raising the lower limit of tensile strength. The results put before you as to the test averages clearly show that the steel makers can work to close margins, and might be induced to work closer still.

So far the development in mild steel has been in the direction of a steady rise of strength. The admiralty, who took the lead in the matter, and who deserve the thanks of the country for their efforts and success in improving the manufacture, adopted 26 and 30 tons as limits. Lloyd's, following them, adopted 27 and 31 tons, and the Liverpool underwriters 28 and 32 tons. I have no doubt further progress will be made in this direction, but it is possibly fortunate that we have advanced no further, seeing that we have yet to decide how we are going to butt, strap, and rivet such strong material. Till we settle this point satisfactorily we are as well to delay.

Regarding the future of steel, it seems to me that there are four matters of doubt and difficulty. The first of these has been already referred to, and is the poor delivery of material as yet attained by the various steel works. This is a matter which may be expected to mend with time and practice, but up to the present it has been by no means the least serious obstacle to an enlarged use of steel.

The second matter is the aggravation of these bad deliveries by the practice of testing adopted by Lloyd's for ship-building material. This practice consists in testing in the yard after delivery of the material, and has been the source of exceeding annoyance, expense, and delay to builders using steel and classing at Lloyd's. It is condemned by the practice of our own and the French admiralties, by the practice of the Liverpool underwriters' registry, and by the practice of Lloyd's registry itself in so far as boiler plates are concerned. It is also, I believe, condemned by every builder who has had the misfortune to suffer from it. Permit me to point out as shortly as possible the main objections to testing in the yards. The first is that it never can be as efficient as testing at the manufacturers' works upon the material as rolled, because there the surveyors can see a bending test made from each plate and bar as they are sheared or cut to length. It must also be remembered that tests can be enforced more rigidly, and will be accepted more willingly at the makers' works, upon small quantities than in the yards upon large quantities, made costly by carriage, and certain to be made more so by return carriage. A second objection is the useless expense thrown on builders of forming a testing staff and erecting a machine or paying for the services of a public machine, when the necessary apparatus and staff already exist and act at the makers' works. A third objection is that the ship-building yard is turned into a storehouse for material which cannot be immediately used, and may not be used at all. Any practical ship-builder will readily understand the pecuniary loss and delay involved in this. A fourth objection, and the most serious, is that the delays and uncertainties involved in testing at the yards, not only tend to, but actually do disorganize these establishments. In the case of my own firm, we have lost some of our best workmen through this cause. I understand Lloyd's committee have it under consideration to remove this very serious difficulty, and I sincerely hope they will do so.

The third difficulty in the way of steel is its supposed greater liability to corrosion than iron. Till now, upon this point, my firm's experience has been small. The *Taeping*, paddle steamer, built of Bessemer steel by us, in 1876, has been so far reported upon most favorably in regard to the matter of corrosion. On the other hand, a small twin-screw, built by us of Siemens-Martin steel, in 1878, for trading in the creeks of the lower Irrawaddy, has been reported as showing a considerable amount of pitting between the light and load water lines, but the reports sent home are not sufficiently full to enable the cause of this pitting to be defined. It may be due to the peculiar brackish water in which the steamer was working, as compared with the fresh water in which the *Taeping* runs. I am strongly inclined to think, however, that this case is purely local and exceptional, and the directors of the company have adopted this view in deciding to build their latest and largest paddle-steamers of the same material.

The fourth difficulty in the way of steel is the doubt entertained by some as to its reliability and safety in actual service in a ship. This doubt it will, I believe, finally and fully overcome. Our experience, already referred to, of its behavior under manipulation ought to tell strongly in its favor, and the report on the docking and repairing of our first sea-going steel steamer, the *Rotomahana*, after running on to and over a rock, ought to convince many not only of the reliability but of the actual safety of properly-made steel. This report I have been permitted by the *Rotomahana's* owners to add to my paper, and it will be found in full in the appendix. Personally I am of opinion that it is a mere matter of time till steel supersedes iron, and its steadily lessening proportionate cost will undoubtedly hasten that time.

TABLE I.—TIME TESTS.

Result of experiments on twelve similar specimens cut from the same hard steel plate to ascertain the effects of applying the load quickly and gradually.

Marks.	Dimensions.	Area.	Breaking strains.		Elongation on 8 inches.		Time.
			Actual.	Per sq. inch.	Inches.	Per cent.	
Load applied quickly:	*Inches.*	*Sq. Ins.*	*Tons.*	*Tons.*			
No. 1	1.69 by .225	.380	15.46	40.6	.98	12.2	2′ 10″
No. 2	1.69 by .225	.380	15.35	40.3	.86	10.7	1′ 15″
No. 3	1.69 by .225	.380	15.35	40.3	1.04	13.0	59″
No. 4	1.69 by .225	.380	15.40	40.5	.74	9.2	59″
No. 5	1.69 by .225	.380	15.57	40.9	1.16	14.5	2′ 15″
No. 6	1.69 by .225	.380	15.66	41.2	.98	12.2	1′ 20″
			Means ..	40.63	....	11.96	1′ 30″
Load applied slowly:							
No. 1*	1.69 by .225	.380	15.04	39.5	.88	11.0	12′ 27″
No. 2*	1.69 by .225	.380	15.33	40.3	.87	10.8	12′ 9″
No. 3*	1.69 by .225	.380	15.13	39.8	.85	10.6	11′ 56″
No. 4*	1.69 by .225	.380	15.08	39.6	.75	9.3	10′ 50″
No. 5*	1.69 by .225	.380	15.04	39.5	1.02	12.7	11′ 50″
No. 6*	1.69 by .225	.380	15.44	40.5	1.16	14.5	11′ 48″
			Means ..	39.86	....	11.48	11′ 50″

Position of samples in plate.

1	2	3	4	5	6
1*	2*	3*	4*	5*	6*

TABLE II.—*Result of experiments on six similar samples cut from the same steel plates tested at different speeds.*

Marks.	Dimensions.	Area.	Breaking strains. Actual.	Breaking strains. Per sq. inch.	Elongation on 8 inches.	Elongation.	Time.
Fast:	*Inches.*	*Sq. in.*				*Per cent.*	
No. 1	1. 62 by . 50	. 810	23. 30	28. 7	2. 03	25. 3	1′ 15″
No. 4	1. 61 by . 50	. 805	23. 83	29. 6	1. 75	21. 8	1′ 46″
			Means	29. 15	....	23. 55	1′ 30″
Medium:							
No. 2	1. 614 by . 495	. 798	22. 81	28. 5	1. 87	23. 4	3′ 54″
No. 5	1. 615 by . 50	. 807	23. 25	28. 8	1. 90	23. 7	5′ 32″
			Means	28. 65	....	23. 55	4′ 43″
Slow:							
No. 3	1. 608 by . 50	. 804	22. 90	28. 4	1. 82	22. 7	13′ 47″
No. 6	1. 61 by . 50	. 805	23. 70	29. 4	1. 82	22. 7	12′ 35″
			Means	28. 9	....	22. 7	13′ 11″

ANNEALING EXPERIMENTS.

TABLE III.—*Results of experiments on eight specimens, cut from the same hard steel plate to ascertain the effect of annealing.*

Marks.	Dimensions.	Area.	Breaking strains. Actual.	Breaking strains. Per square inch.	Elongation on 8 inches. Inches.	Elongation on 8 inches. Per cent.
Unannealed:	*Inches.*	*Sq. ins.*	*Tons.*	*Tons.*		
No. 2	1. 71 by . 25	. 427	14. 16	33. 1	1. 37	17. 1
No. 4	1. 71 by . 25	. 427	14. 06	32. 9	1. 35	16. 8
No. 6	1. 71 by . 25	. 427	14. 06	32. 9	1. 37	17. 1
No. 8	1. 71 by . 25	. 427	14. 12	33. 0	1. 25	15. 6
			Means	32. 97		16. 65
Annealed:						
No. 1	1. 71 by . 25	. 427	12. 11	28. 3	2. 08	26. 0
No. 3	1. 71 by . 25	. 427	12. 32	28. 8	1. 97	24. 6
No. 5	1. 71 by . 25	. 427	12. 29	28. 7	1. 75	21. 8
No. 7	1. 71 by . 25	. 427	12. 12	28. 3	1. 93	24. 1
			Means	28. 52		24. 12

Duplicate samples of above were bent cold, to a curve with a diameter equal to the thickness of the plate. All showed cracks, without any perceptible difference between the annealed and unannealed samples.

Position of samples in plate.

No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Annealed.		Annealed.		Annealed.		Annealed.	

ANNEALING EXPERIMENTS.

TABLE IV.—*Results of experiments on eight specimens, cut from the same soft steel plate, to ascertain the effect of annealing.*

Marks.	Dimensions.	Area.	Breaking strains.		Elongation on 8 inches.	
			Actual.	Per square inch.	Inches.	Per cent.
Unannealed:	*Inches.*	*Sq. ins.*	*Tons.*	*Tons.*		
No. 2	1.663 by .237	.394	10.60	26.9	1.90	23.7
No. 4	1.675 by .240	.402	10.60	26.3	1.77	22.1
No. 6	1.680 by .241	.404	10.82	26.7	1.94	24.2
No. 8	1.680 by .241	.404	10.71	26.5	2.19	27.3
			Means..	26.60		24.32
Annealed:						
No. 1	1.690 by .234	.395	9.39	23.7	2.32	29.0
No. 3	1.650 by .240	.396	9.48	23.9	2.52	31.5
No. 5	1.660 by .240	.400	9.79	24.4	2.31	28.8
No. 7	1.656 by .242	.400	9.70	24.2	2.42	30.2
			Means..	24.05		29.87

Duplicate samples of above were folded close cold, Nos. 2 and 4 (unannealed) and Nos. 1 and 3 (annealed) having been previously tempered by heating to redness and cooling in water at 82° F. All the samples stood the test except Nos. 4 and 8, both of which showed cracks.

Position of samples in plate.

No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Annealed.		Annealed.		Annealed.		Annealed.	

Annealing Experiments.

Table V.—*Results of experiments on eight specimens, cut from the same steel plate, to ascertain the effect of annealing.*

[Four samples were annealed and four unannealed.]

Marks.	Dimensions.	Area.	Breaking strains.		Elongation on 8 inches.	
			Actual.	Per square inch.	Inches.	Per cent.
	Inches.	*Square inches.*	*Tons.*	*Tons.*		
Unannealed:						
No. 2	1.486 by .525	.780	22.49	28.8	2.03	25.3
No. 4	1.490 by .524	.780	22.36	28.6	2.05	25.6
No. 6	1.500 by .527	.790	22.63	28.6	2.06	25.7
No. 8	1.510 by .530	.800	22.58	28.2	1.90	23.7
			Means..	28.55		25.07
Annealed:						
No. 1	1.480 by .525	.777	20.98	27.0	2.21	27.6
No. 3	1.486 by .525	.780	21.24	27.2	2.13	26.6
No. 5	1.490 by .531	.791	21.20	26.8	2.06	25.7
No. 7	1.500 by .527	.790	21.20	26.8	2.22	27.7
			Means..	26.95		26.90

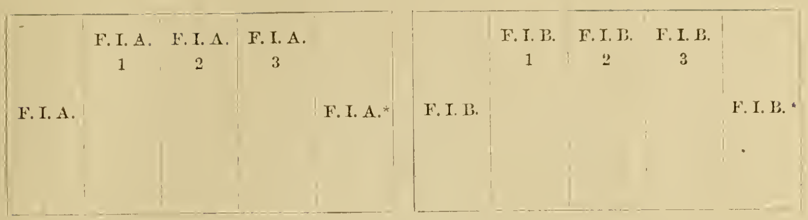
Position of samples in plate.

No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Annealed.		Annealed.		Annealed.		Annealed.	

Table VI.—*Results of experiments to ascertain the tensile strength and ductility of specimens cut from two forged iron plates.*

Marks.	Dimensions.	Area.	Breaking strains.		Elongation on 8 inches.	
			Actual.	Per square inch.	Inches.	Per cent.
	Inches.	*Square inches.*	*Tons.*	*Tons.*		
F. I. B. 1	1.00 by .795	.795	17.09	21.4	1.28	16.0
F. I. B. 2	.99 by .795	.787	17.45	22.1	1.53	19.14
F. I. A. 3	1.00 by .780	.780	15.26	19.5	.80	10.0
F. I. B. 3	1.00 by .800	.800	17.45	21.8	1.58	19.7
F. I. A. 1	.985 by .770	.758	15.75	20.7	1.17	14.6
F. I. A. 2	.970 by .780	.756	13.88	18.3	.70	8.7
			Means..	20.63		14.9

Position of samples in plates.



Deflection experiments on specimens cut from the same plates as above samples

[Distance apart of bearing centers, 18 inches.]

Marks.	Size of specimen.										
F. I. A.	4.95″ by .78″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	8,800	
		Set in inches	.03	.06	.09	.11	.38	1.1	2.1	Still deflecting.	
		Permanent set in inches	....	....	....	None.	.25	.92	1.9		
F. I. A.*	4.95″ by .73″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	8,600	
		Set in inches	.03	.06	.10	.20	.70	1.67	3.1	Still deflecting	
		Permanent set in inches	....	....	None.	.07	.59	1.49	2.9		
F. I. B.	4.96″ by .79″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	
		Set in inches	.03	.05	.09	.14	.40	.98	1.88	Still deflecting.	
		Permanent set in inches	....	None.	.01	.04	.29	.85	1.70		
F. I. B.*	4.96″ by .80″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	9,800
		Set in inches	.05	.08	.11	.16	.23	.44	1.05	2.07	Still deflecting.
		Permanent set in inches	....	None.	.01	.02	.11	.28	.88	1.88	
		Mean set	.035	.0625	.0975	.1525	.4275	1.0475	2.0325		
		Mean permanent set	....	....	.010	.0325	.310	.885	1.845		

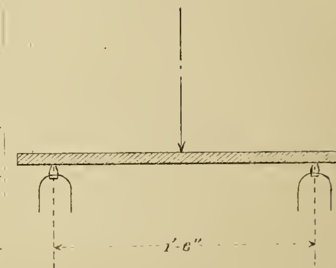
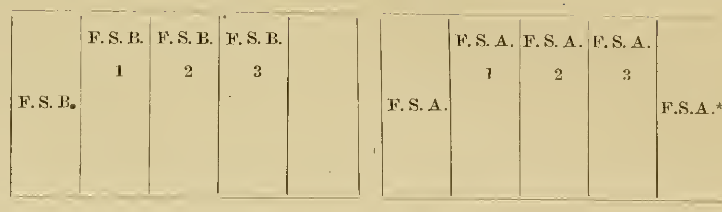


TABLE VII.—*Results of experiments to ascertain the tensile strength and ductility of specimens cut from two forged steel plates.*

Marks.	Dimensions.	Area.	Breaking strains. Actual.	Breaking strains. Per sq. in.	Elongation on 8 inches.	Elongation on 8 inches.	
	Inches.	*Sq. ins.*	*Tons.*	*Tons.*	*Inches.*	*P'r cent.*	
F. S. B. 1	1.09 by .82	.893	20.98	23.4	1.27	15.8	Imperfectly welded.
F. S. B. 2	1.11 by .82	.910	21.15	23.2	1.06	13.2	Do.
F. S. B. 3	1.02 by .81	.826	19.90	24.0	1.90	23.7	
F. S. A. 1	1.01 by .80	.808	19.37	23.9	1.75	21.8	
F. S. A. 2	1.14 by .80	.912	22.32	24.4	1.60	20.0	
F. S. A. 3	1.06 by .80	.848	20.40	24.0	1.80	22.5	
			Means..	23.81	....	19.5	

Position of samples in plates.



Deflection experiments on specimens cut from same plates as above samples.

[Distance apart of bearing centers, 18 inches.]

Marks.	Size of specimen.											
F. S. A.	5″ by .775″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	10,400
		Set in inches	None	.03	.04	.09	.23	.92	1.64	2.45	3.84	Still de-
		Permanent set in inches	....	.01	.01	.02	.12	.78	1.53	2.37	3.74	flecti'g.
F. S. A.*	4.93 by .78″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	9,400	
		Set in inches	None	.04	.06	.08	.12	.94	1.51	2.74	Still de	
		Permanent set in inches	....	....	....	None	.02	.54	1.39	2.64	flecti'g.	
F. S. B.	4.9 by .78″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	9,020	
		Set in inches	.02	.06	.10	.14	.20	.75	1.64	3.22	Still de-	
		Permanent set in inches	....	None	.01	.04	.10	.60	1.56	3.07	flecti'g.	
F. S. B.*	4.93 by .78″	Strain in pounds	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	9,600	
		Set in inches	None	.04	.07	.10	.14	.50	1.3	2.2	Still de-	
		Permanent set in inches	....	....	....	None	.02	.36	1.11	1.98	flecti'g.	
		Mean set	....	.0425	.0675	.1025	.1725	.7025	1.5225	2.6525		
		Mean permanent set	....	....	.0100	.0300	.0650	.5700	1.3975	2.5150		

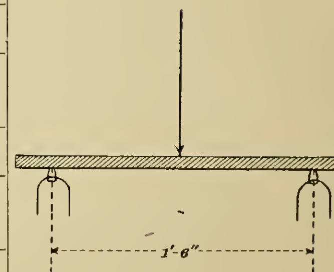
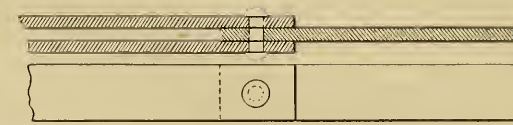


TABLE VIII.—*Experiments on the shearing strength of rivets, steel and iron.*

[One rivet in each specimen subject to double-shearing action.]

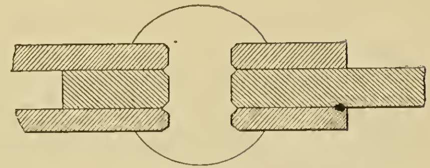
Hand sketch of specimens:



	Diameter of hole.	Area of hole.	Double area of hole.		Shearing force. Total.	Shearing force. Per sq. in.	
	Inches.	*Inches.*	*Sq. ins.*				
¾-inch steel rivets made from homogeneous steel....	.82	.528	1.056	Riveted by Arroll's hydraulic machine....	25.40	24.0	Sheared on both surfaces.
	.82	.528	1.056		26.52	25.1	Sheared on one surface.
	.82	.528	1.056	Riveted by hand	23.44	22.2	Sheared on both surfaces.
	.82	.528	1.056		21.70	20.5	Sheared on one surface.
¾-inch steel rivets made from scrap steel	.82	.528	1.056	Hydraulic	24.60	23.3	Sheared on one surface.
	.82	.528	1.056		25.44	24.1	Do.
	.82	.528	1.056	Hand	21.96	20.8	Do.
	.82	.528	1.056		22.85	21.6	Do.
¾-inch iron rivets made from best scrap iron........	.805	.509	1.018	Hydraulic	20.05	19.7	Sheared on both surfaces.
	.810	.515	1.03		19.82	19.2	Sheared on one surface.
	.815	.522	1.044	Hand	19.55	18.7	Sheared on both surfaces.
	.815	.522	1.044		20.09	19.2	Do.

TABLE VIII—Continued.

Holes in next four slightly countersunk, thus:

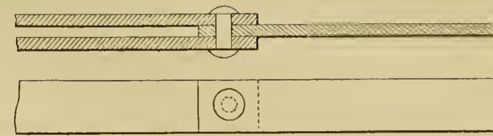


	Diameter of hole.	Area of hole.	Double area of hole.		Shearing force. Total.	Shearing force. Per sq. in.	
	Inches.	*Inches.*	*Sq. ins.*				
$\frac{3}{4}$-inch scrap-steel rivets	.80	.503	1.006	Hydraulic	25.00	24.8	Sheared on one surface.
	.80	.503	1.006		25.09	24.9	Sheared on both surfaces.
	.815	.522	1.044	Hand	26.16	25.1	Sheared on one surface.
	.80	.503	1.006		24.42	24.3	Do.

All the holes in the above were drilled.

TABLE IX.—*Experiments on the shearing strength of rivets, steel, and iron.*

[One rivet in each specimen subject to double-shearing action.]



	Diameter of holes.	Area of holes.	Double area of holes.		Shearing. Total.	Shearing. Per sq. in.	
	Inches.	*Inches.*	*Sq. ins.*				
¾-inch steel rivets made from homogeneous steel	.825	.535	1.07	Hydraulic	26.25	24.5	Sheared on both surfaces.
	.815	.522	1.044		25.93	24.8	Do.
	.825	.535	1.07	Hand	27.36	25.6	Sheared on one surface.
	.815	.522	1.044		26.03	24.9	Do.
¾-inch steel rivets made from scrap steel	.815	.522	1.044	Hydraulic	23.84	22.8	Sheared on both surfaces.
	.815	.522	1.044		24.11	23.1	Do.
	.815	.522	1.044	Hand	23.08	22.1	Do.
	.815	.522	1.044		22.95	22.0	Do.
¾-inch iron rivets made from best scrap iron	.815	.522	1.044	Hydraulic	19.69	18.9	Sheared on one surface.
	.815	.522	1.044		20.18	19.3	Sheared on both surfaces.
	.82	.528	1.056	Hand	20.40	19.3	Sheared on one surface.
	.82	.528	1.056		*18.66	17.7	Do.

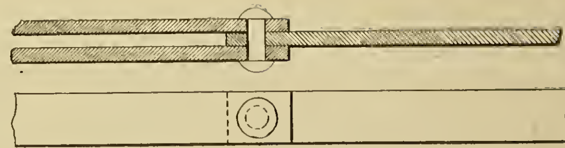
* Rivet fractured also between the shearing surfaces as by tensile strain.

Holes in next four slightly countersunk. See sketch, Table VIII.

¾-inch scrap-steel rivets	.825	.535	1.07	Hydraulic	24.86	23.2	Sheared on one surface.
	.815	.522	1.044		25.36	24.3	Do.
	.825	.535	1.07	Hand	24.55	22.9	Do.
	.83	.528	1.056		26.30	24.9	Do.

All the holes in the above were drilled.

TABLE X.—*A combination of Tables VIII and IX.*



	Diameter of holes.	Area of holes.	Double area of holes.		Shearing force. Total.	Shearing force. Per sq. in.	Means.	Means.
	Inches.	*Inches.*	*Inches.*					
¾-inch steel rivets made from homogeneous steel	.82	.528	1.056	Riveted by Arrol's hydraulic machine.	25.40	24.0	24.55	24.6
	.82	.528	1.056		26.52	25.1		
	.825	.535	1.07		26.25	24.5	24.65	
	.815	.522	1.044		25.93	24.8		
	.82	.528	1.056	Riveted by hand	23.44	22.2	21.35	23.3
	.82	.528	1 056		21.70	20.5		
	.825	.535	1.07	do	27.36	25.6	25.25	
	.815	.522	1.044		26.03	24.9		
¾-inch steel rivets made from scrap steel	.82	.528	1.056	Hydraulic	24.60	23.3	23.7	23.3
	.82	.528	1.056		25.44	24.1		
	.815	.522	1.044	do	23.84	22.8	22.95	
	.815	.522	1.044		24.11	23.1		
	.82	.528	1.056	Hand	21.96	20.8	21.2	21.6
	.82	.528	1.056		22.85	21.6		
	.815	.522	1.044	do	23.08	22.1	22.05	
	.815	.522	1.044		22.95	22.0		

¾ inch iron rivets made from best scrap iron	.805	.509	1.018	Hydraulic	20.05	19.7	19.45	19.3
	.810	.515	1.030		19.82	19.2		
	.815	.522	1.044	do	19.69	18.9	19.1	
	.815	.522	1.044		20.18	19.3		
	.815	.522	1.044	Hand	19.55	18.7	18.95	18.7
	.815	.522	1.044		20.09	19.2		
	.82	.528	1.056	do	20.40	19.3	18.5	
	.82	.528	1.056		18.66	*17.7		

* Fractured also between the shearing surfaces as by tensile strain.

Holes in next eight slightly countersunk. See sketch, Table VIII.

¾-inch steel rivets made from scrap steel	.80	.503	1.006	Hydraulic	25.00	24.8	24.85	24.3
	.80	.503	1.006		25.09	24.9		
	.825	.535	1.07	do	24.86	23.2	23.75	
	.815	.522	1.044		25.36	24.3		
	.815	.522	1.044	Hand	26.16	25.1	24.7	24.3
	.80	.503	1.006		24.42	24.3		
	.825	.535	1.07	do	24.55	22.9	33.9	
	.82	.528	1.056		26.30	24.9		

TABLE XI.—OCEAN STEAMERS CLASSED AT LLOYD'S.

Averages of steel tests.

[Rejected plates or bars not included.]

No. of ship.	Angles or plates.	Breaking strain per square inch.	Elongation on 8 inches.
		Tons.	*Per cent.*
224	Angles, &c	28.2	25.3
	Plates	29.0	21.9
		28.6	23.6
225	Angles, &c	28.80	22.70
	Plates	29.65	22.53
		29.22	22.61
226	Angles, &c	30.21	21.67
	Plates	29.27	21.58
		29.74	21.62
233	Angles, &c	29.41	23.38
	Plates	28.46	22.16
		28.93	22.77
General average		29.12	22.65

APPENDIX.

REPORT OF REPAIRS TO S. S. ROTOMAHANA, EXECUTED IN THE GRAVING DOCK, PORT CHALMERS, AND RENDERED NECESSARY BY THE STEAMER TOUCHING ON A ROCK WHILE RUNNING AN EXCURSION FROM AUCKLAND TO THE GREAT BARRIER ISLAND, ON NEW YEAR'S DAY, 1880.

On examining the bottom it was found that on the starboard bilge, at the bulkhead between the fore-hold and the stoke-hole, about 20 feet of the fourth strake from the keel was all more or less indented, one plate particularly, 14 feet by 3 feet 7 inches by ½ inch thick, being very badly indented between the frames. This plate we decided to remove, and started doing so at 7 p. m. on the 7th instant. The removal occupied twenty-four hours, as all our tools broke in the work, and a new set had to be specially made to stand the steel. The plate looked so bad that it was doubtful whether it was worth while spending any time over it; however, we decided to give it a fair trial; and it was put in the furnace and heated for two hours, then taken out and hammered on the blocks. This process had to be repeated three times before the rollers would take it in, but when it had passed through the rollers it really looked like a new plate perfectly sound and good. In working it stretched three-sixteenths of an inch, but by paring a little off the ends, the rivet holes at both the landings and the butts came in exactly as required for a fine fit. Seven of the frames were badly bent, with a sharp curve tending both inwards and aft, two being bulkhead frames with double angles and very strong.

The floors were cut and the frames thoroughly examined, but we found no sign of crack or strain in the material. The frames were heated and restraightened and riveted to the floors. All the riveting was completed by 6 p. m., on the 10th instant. It may be here stated that had the frames been composed of iron instead of the splendid ductile material of which they are composed, they would all require to have been renewed, and even then they would not have made such a complete job as the present. The ironwork inside was cemented, and the ceiling laid and bolted down as before. The bottom was coated with McBean's anti-fouling composition, and the top sides repainted.

The steamer was safely floated out of dock on the 10th instant, at 11 p. m., and sailed for Melbourne at 5 p. m. next day.

A. CAMERON,
Marine Superintendent.

JANUARY 15, 1880.

[Extract from letter of managing director of the Union Steamship Company of New Zealand referring to the Rotomahana's touching on a rock.]

This experience has shown clearly the immense superiority of steel over iron. There is little doubt that had the *Rotomahana* been of iron, such a rent would have been made in her that she would have filled in a few minutes. A number of frames were set back by the force of the blow, the bulkhead was bulged and the plate was corrugated, and yet there did not appear one crack anywhere. We would, however, require better tools than we have at present if we are to have anything further of this nature, as the steel proves very difficult to work.

ON STEEL FOR SHIP-BUILDING.

BY HENRY H. WEST, *Chief Surveyor to the Underwriters' Registry for Iron Vessels, member.*

[Read at the twenty-first session of the Institution of Naval Architects, March 19, 1880; the Right Hon. Lord HAMPTON, G. C. B., D. C. L., president, in the chair.]

In a paper read before this Institution in 1875, Mr. Barnaby, chief naval architect of the Royal Navy, used these words:

The question we have to put to the steel makers is: What are our prospects of obtaining a material which we can use without such delicate manipulation and so much fear and trembling? * * * We want a perfectly coherent and definitely carburrized bloom or ingot, of which the rolls have only to alter the form in order to make plates, with qualities as regular and precise as those of copper and gun-metal, and we look to the manufacturers for it.

It is no part of my present purpose to inquire whether all the "delicate manipulation" was necessary, which Mr. Barnaby described in the paper from which I have quoted. It is enough that, five or six years ago, steel was used with "fear and trembling." It is largely due to the influential example of the admiralty, and to the firmness with which Mr. Barbaby and his staff have insisted on uniformity of quality, that we now have steel which may be used with as much confidence as iron, and which demands no exceptional precautions.

The test standards of the admiralty and the classification societies are too well known to need detailed recapitulation here. They will be found *in extenso* in the appendix to this paper. They all consist of tensional tests, supplemented by cold bending tests, after heating the samples to a red heat and suddenly cooling them in water. The admiralty and Lloyd's superadd to these the requirement of a definite percentage of elongation, before fracture under tensional strain. In the tests made by the Liverpool Underwriters' Registry this elongation is always noted, but no definite percentage of extension is demanded, reliance being placed on the temper-bending tests to show whether the material is of suitable ductility.

The principal difference between the standards of the Admiralty. Lloyd's, and the Liverpool Underwriters' Registry is in the limits of ultimate tensional resistance, the Admiralty requiring that the breaking strain shall lie between 26 and 30 tons per square inch, Lloyd's between 27 and 31 tons, and the Liverpool Underwriters' Registry between 28 and 32 tons.

A material which is stronger than the best iron, and which will double up cold without fracture, has very great charms for the practical ship-builder. The ductility of such material makes it well suited for the ordinary processes of the ship-yard, where neither drilled rivet-holes nor careful annealing can as yet be economically practiced. Further, since collisions and strandings are constantly occurring, the use, in the hulls of vessels, of a material possessing the very excellent quality of bending without breaking, may easily be the means of preventing accidents of this character from ending in total loss.

Such a material is now produced by the steel makers in response to Mr. Barnaby's challenge, and they have practically given us steel plates and bars with qualities "as regular and precise as those of copper and gun metal."

Having gained this vantage ground, we may fairly look round to see what our next step may be.

The object which ordinary merchant ship-owners have in view in adopting steel as a material of construction is to secure with the same strength a lighter vessel than can be built of iron, and only by this inducement can the greater cost of the material be met. An important increase of tenacity as compared with iron is therefore a commercial necessity.

So far as the qualities of softness and ductility contribute to the safety of life and property at sea, and so long as they are necessary to dispose of that "fear and trembling" with which steel has so long been regarded, I would be the last to depreciate them. But, while it is admitted that these qualities have made steel a material which with the simplest appliances and ordinary care may be used in any ship-yard, it can hardly be claimed for the lower tensional limit of the Admiralty standard that it provides a material for which important reductions in scantling can be allowed. The tenacity of good iron approximates too closely to that of such very mild steel to warrant any marked difference between them in the scantlings adopted.

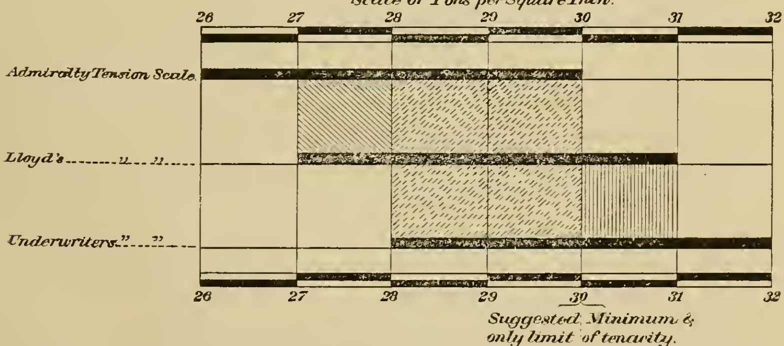
This would appear to have been felt by the authorities of Lloyd's when, in 1877, they issued their standard tests for steel with a higher limit of tenacity than the Admiralty scale by 1 ton per square inch.

The committee of the Liverpool Underwriters' Registry also felt the necessity of securing greater strength in the material, if any important reduction of scantling was to be allowed, and they adopted as their minimum standard of tenacity 28 tons per square inch.

This limit was fixed in great measure out of deference to the Admiralty regulations. Ship-building steel is as yet only made at a few establishments, and since Admiralty orders were almost sure to be executed concurrently with orders for the Mercantile Marine, it was manifestly convenient, in aiming at a higher standard of strength, to contrive the limits to overlap; thus material of a tenacity of 28 to 30 tons per square inch would pass both the Admiralty and the Liverpool Underwriters' Registry tension tests, and would also fall within Lloyd's limits. Material of 28 to 31 tons would pass with both Lloyd's and the Liverpool Underwriters' Registry, and incidentally I may note that 27 to 30 tons would pass both the Admiralty and Lloyd's. (See Fig. 1.)

Fig. 1.

Scale of Tons per Square Inch.



Had it not been for this practical convenience the Liverpool Underwriters' Registry was ready at once to accept 30 tons as the lowest limit of tensile strength.

In the years 1863 and 1864 several vessels were built of steel at Liverpool and elsewhere, under the survey of the Liverpool Underwriters' Registry, and although these vessels were not all built for classification, the material and workmanship were submitted to careful examination. It is admitted that the testing, then, was neither as extensive nor as systematic as it is now, but the result of experience at that time was that a kindly-working and fairly uniform material could be obtained, with tension limits of 30 to 36 tons per square inch.

A steel vessel built in 1864 has recently passed under the survey of the society with which I have the honor to be connected.

Some of the plates were found pitted and so corroded that it was necessary to remove them, and a plate found broken by an accidental damage was also removed. A convenient opportunity was thus afforded to ascertain experimentally some of the qualities of the steel which had done good service during a period of fifteen or sixteen years.

I am indebted to Mr. Denny and to Mr. Kirk for testing experiments on two of these plates, the details of which did not reach me in time for incorporation in this paper, but I may state in general terms that the ultimate tenacity of the strongest plate rose to 44 tons per square inch, with an elongation of 13.6 per cent. in 4 inches. In the softer plate the elongation was 21.4 per cent. A cold-bending test in each case was satisfactory, but the temper-bending test was not so successful. The chemical analysis by the Glasgow city analyst gave carbon (combined) 0.565 and 0.510 per cent. for the hard and soft plates respectively. This large proportion of carbon no doubt accounts for the unsatisfactory temper-bending results. Similar tests were made upon ordinary Siemens-Martin steel as at present used, in which the results were superior to the old steel in the temper-bending sample, but otherwise did not seem to have any material advantage. The samples lie on the table for inspection.

The present testing practice of the Liverpool Underwriters' Registry is as follows:

From every parcel of plates or bars, one in each fifty or fraction of fifty is selected by the testing surveyor as a representative sample. From this plate or bar, pieces are cut in the ordinary way for tension and for temper-bending tests; they are taken lengthways or crossways of the plate indifferently, and occasionally in both directions; they are taken from the crop edges and ends of the plates when these are large enough to allow it, so that if the tests are successful the plates are not spoiled for their intended purpose. The tension pieces, after being suitably shaped, are broken in the testing machine. The elastic limit is approximately noted. The breaking weight is carefully observed, pains being taken to see that each increment of load has produced its full effect before the load is further increased. The gross elongation and the fractured area are then measured and noted. The main object of the tensile test is to ascertain the ultimate strength of the material, and to secure that the weakest plates shall have a tenacity of at least 28 tons per square inch.

Temper-bending tests are also made to ascertain whether the material will harden to such an extent under sudden and extreme changes of temperature as to unfit it for the mechanical operations of working into place, and also to ascertain whether the material is capable of withstanding extreme changes of form without fracture.

Though the amount of elongation under tension is noted, it is not considered a matter of very vital importance, because the bending test is itself an elongation test of a very complete kind. If, before bending, a series of equidistant points are marked upon what will be the convex side of a bending sample, and are again measured after bending, it will be found that the distance between them at and about the crown of the bend has materially increased, and that a local elongation has accrued at that point amounting to even 40 or 50 per cent.

In the diagram, Fig. 2 represents a temper-bending sample, Fig. 3 being the same sample after bending; Fig. 4 shows the sample, with

Fig. 2.

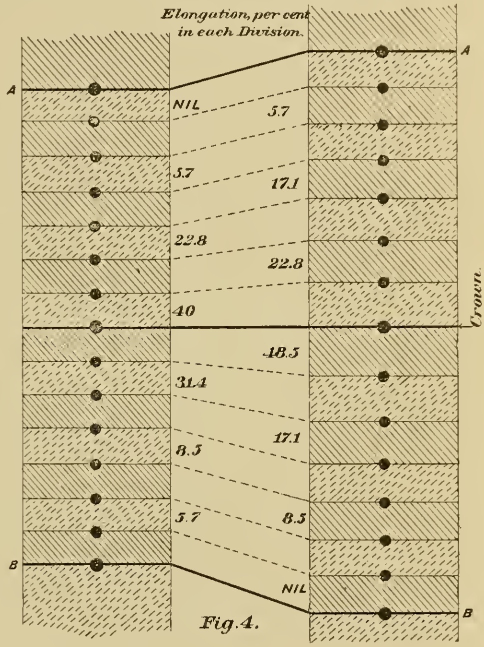
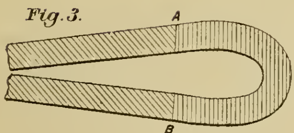


Fig. 4.

Fig. 3.



the equal divisions marked upon it, and also an expansion of its convex surface after bending. The percentages of elongation are taken from the same actual example. The part elongated by the process of bending is marked A to B in each figure.

In addition to the tensile and temper-bending tests the surveyor, at his discretion, subjects angles, tees, and tee bulbs to opening and closing, and "ram's-horn" tests, with a view of excluding any material having a tendency to reediness.

I have hitherto referred principally to a minimum tensional limit; but general experience has indicated that the stronger the steel the more is it liable to chill and harden, and the less is it capable of extreme changes of form without fracture, so that a maximum limit of tenacity has been adopted as an indirect check on the manufacture and use of hard or brittle material.

I submit, however, that this ground is already amply covered by the temper-bending tests, and if these prove satisfactory a maximum limit of tension becomes unnecessary; indeed, if the bending tests show the steel to be of satisfactory ductility the stronger it is the better.

It is sometimes objected to by steel makers and others that the number of test samples selected, and the severity of the tests themselves, materially increase the cost of ship-builders' steel; in fact, that by protracted and costly experimental tests, which, in addition to limiting the quality of steel available for ship-building purposes, are in themselves an important item in the cost of production, the classification societies are obstructing the free use of a material which is admittedly superior to the best iron.

So far as this objection implies that we are demanding too good a quality of steel I have no sympathy with it. A substantial reduction of scantling is claimed on account of the good qualities of steel, and we can only make sure that these good qualities exist by a complete system of testing. As yet we have seen no reason to relax either the number of the representative samples or the severity of the tests themselves.

So far, however, as the objection is directed against a tendency to convert the tests into an experimental investigation it has my most hearty support. Steel must be tested, just as the products of many other manufactures must be carefully examined in comparison with definite standards before they can be issued, but the more we can simplify the examining process the less will be the cost of production.

We have already seen that only two principal tests are necessary upon each representative sample—one a test of tenacity, the other a test of ductility; we have also found that the tenacity test need only have a minimum limit, providing it is always accompanied by a sufficient test of ductility. The tests then being directed to one or two specific points, and to these only, it is easy to see that a system of testing might readily be contrived, which, while simple to the last degree, should uncompromisingly require conformity to the standards, and be sufficiently extensive to secure complete representation of the whole parcel under examination.

I do not now discuss whether our bending tests should be modified in any degree, though I am aware something may be said in favor of such a course. For the present I incline to adhere to the familiar admiralty bending test, which has done us such good service.

If I have been fortunate enough to carry you with me as far as I have gone, you will be prepared to accept a minimum standard of tenacity without any maximum limit. What shall this standard be? At present the admiralty, Lloyd's, and the Liverpool Underwriters' Registry have fixed as their minima 26, 27, and 28 tons per square inch, respectively. But if we are to secure a quality of material which will allow important reduction of scantlings, and yet retain the stiffness and the strength which we look for in our ships and steamers, we must have a higher tensional resistance than any of the minima which I have quoted. Looking over the tension scales of the admiralty, Lloyd's, and the Liverpool

Underwriters' Registry (Fig. 1), it will at once be seen that 30 tons per square inch comes within the scope of every scale, and thus carries with it the stamp of approval of authorities whose very nature is caution. That this, and even greater strength, can be produced without any dangerous sacrifice of ductility has been abundantly demonstrated in the daily tests with which we are all more or less familiar; and it is with respectful deference, but with perfect confidence, that I recommend this standard to you for general adoption in ship-building material.

APPENDIX.

ADMIRALTY TESTS FOR PLATE, ANGLE, BULB, AND BAR STEEL.

Strips cut lengthwise or crosswise, to have an ultimate tensile strength of not less than 26 and not exceeding 30 tons per square inch of section, with an elongation of 20 per cent. in a length of 8 inches.

The beam, angle, bulb, and bar steel to stand such forge tests, both hot and cold, as may be sufficient in the opinion of the receiving officer to prove soundness of material and fitness for service.

Strips cut crosswise and lengthwise, 1½ inches wide, heated uniformly to a low cherry red and cooled in water of 82° F., must stand bending in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested. The strips are all to be cut in a planing machine, and to have the sharp edges taken off. The ductility of every plate, beam, angle, &c., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold by the hammer.

All steel to be free from lamination and injurious surface defects.

One plate, beam, angle, &c., to be taken for testing from every invoice, provided the number of plates, beams, angles, &c., does not exceed 50. Steel may be received or rejected without trial of every thickness on the invoice. The pieces of plate, beam, angle, &c., cut out for testing are to be of a parallel width from end to end, and for at least 8 inches of length.

LLOYD'S TEST FOR STEEL USED IN SHIP-BUILDING.

Strips cut lengthwise or crosswise of the plate, and also angle and bulb steel, to have an ultimate tensile strength of not less than 27 and not exceeding 31 tons per square inch of section, with an elongation corresponding to 20 per cent. on a length of 8 inches before fracture.

Strips cut from the plate, angle, or bulb steel, to be heated to a low cherry red, and cooled in water of 82° F., must stand bending double round a curve of which the diameter is not more than three times the thickness of the plate tested.

UNDERWRITERS' REGISTRY TESTS FOR STEEL USED IN SHIP-BUILDING.

The material is to be tested in the presence of the surveyor, as in his judgment may appear desirable, both as to tensional resistance and as to cold bending.

Angle, tee, and bulb bars to be submitted to closing, and opening, and "ram's-horn" tests, as the surveyor may direct.

The ultimate tensional resistance of plates and bars to be not less than 28 nor more than 32 tons per square inch. The cold-bending test to be as follows: The sample to be tested to be heated to a full red, and quenched in water, and afterwards bent double cold without fracture, with a curvature of which the inner radius does not exceed one and a half time the thickness of the plate tested.

The tests to be applied as frequently as the surveyor may deem necessary, but must not be less than one in every parcel, or in each fifty plates or bars, or fraction of fifty.

If necessary, arrangements may be made for testing the material at the steel-makers' works, in the presence of the surveyor.

DISCUSSION.

Mr. FREDERICK J. BRAMWELL, F. R. S. (associate member of Council): My lord and gentlemen, I for one am extremely glad that a gentleman in the official position of Mr. West has made the suggestion that in future the testing should not comprise a maximum of endurance, but simply a minimum of bending test. I have said, I believe, at discussions of this Institution, but certainly at discussions which have taken place on this question elsewhere, that to my mind, although it might be a convenient mode of attaining a result, and perhaps a prudent one, in the outset of a new manufacture on a large scale, to suggest that there should be a maximum as well as a minimum; because it being ascertained if that maximum were not exceeded, certain qualities necessary to pass the bending test would certainly be obtained, yet nevertheless to *persevere* in maximum power in bearing a load was an illogical and unwise thing. It seems to me clear that what you want is a material as strong as possible, consistent with its durability, and therefore it is most unwise that you should limit the makers of the material to make it as weak as a certain standard after you have satisfied yourself it is ductile. I think the suggestion coming from Mr. West must command the respect of this Institution, and I am perfectly sure if it is agreed in, and the maximum line be demanded in the making of these experiments which are required, it will be found, from time to time, that the standard of strength rises without any depreciation of ductility, and it will not be many years before this Institution will have brought before it suggestions from gentlemen in Mr. West's position, or from Mr. West himself, that the minimum may be increased, and that the 30-tons maximum should become 32 or 34.

Dr. C. W. SIEMENS, F. R. S., D. C. L. (associate member of Council). My lord and gentlemen, we have listened to two, in my opinion, very valuable papers, one written by an eminently practical ship-builder, and the other by a gentleman who has had great experience in the testing of a material now largely used in construction. I agree with many of the opinions advanced in both of these papers. Both seem to advocate advance in the same direction, but there are certain points on which I must, with all respect to the authors, differ from them in opinion. The all important question which has been put forward in these papers is the question of the absolute maximum strength to be required or accepted in mild steel. If you take a bar of comparatively hard steel—steel that will stand 50 tons to the inch—it will at the time of its breakage have elongated perhaps only 6 or 7 per cent. But take a material of 30 tons to the inch and it will have elongated 20 per cent. Now, to begin with, it is not strictly correct to say that this latter material broke under a tensile strain of 30 tons to the inch, because whatever might have been the sectional area of the original bar at the time it broke, it had bodily elongated 20 per cent.; therefore the strain was no longer 30 tons to the inch, but 36 tons to the inch, and I claim for the mild material at any rate this advance of strength. What, however, is the condition of things before we have reached this ultimate limit? Take one bar with a breaking strain according to the usual test of 30 tons to the inch, and another of 50; weight both these bars with 5 tons to the inch, and you will find that these bars have elongated to exactly the same extent. Weight both bars to the limit of 10 tons to the inch, and again it will be found that the elongation is the same. Therefore up to that point at any rate I claim as great a strength for the mild steel as for the hard. Increase that strain even to 15 tons to the inch, and the elongation will still be the same. Take the load off both bars, and they will both come back to the original lengths. Go to 20 tons and you will find a difference. The hard steel—the steel that will break at 50 tons to the inch—will again return to its original length when the load is taken off, whereas the material breaking with 30 tons to the inch of the original section will show a permanent elongation. This, you will say, is a sign of weakness, and condemns that bar; but I would venture to maintain that this is a sign of the strength of the latter bar. Up to the point of 15 tons to the inch the two materials are precisely alike, and if the naval constructor takes care that no portion of his ship, viewed as a girder, should receive a greater strain than 15 tons, both materials are able to bear the strain, and they will both deflect to precisely the same extent. But it may be said materials may accidentally be subjected to a higher strain, and in that case greater strength will be needed. Take the strain of bumping a ship against a rock, or the ground, or against another ship. The hard steel will no doubt stand a heavier blow, but there is just the possibility that when the blow comes it will fracture, whereas the soft steel we know will yield almost to any extent to sudden impact. Therefore, as far as the safety of the structure against an action of that description is concerned, the soft metal is decidedly the stronger. Then, again, it has been put very forcibly by Mr. Denny, that very mild steel requires no annealing; that it is very nearly as strong and as ductile unnealed as annealed; whereas if you have a harder material—a material containing more carbon—annealing becomes necessary after bending, after punching certainly, and even after drilling. It becomes a necessity. But by annealing you take away some 20 per cent. of strength, and therefore, I say it is much better to make at once a material that requires no annealing, that does not assume a strained condition when put into a definite shape, and which maintains its strength. The mild material without annealing is as strong, or at any rate, is as ductile practically, as after annealing; and I believe at some yards punching without annealing has been resorted to without any practical drawback. These are powerful arguments, I think, in favor of the very soft material. There is one more argument which I wish to adduce. That is, if the material of the low elastic limit happens to be chilled accidentally after manufacture, this chilling does not interfere with its strength to resist blows or sudden strains; whereas with a hard material you will even come to the point of contemplating with great concern the safety of the structure when made. I believe it is much safer to adhere to a material which stands an extreme bending test, and to assign to it the same practical limit of load which you would to a harder material. In dealing with wrought iron the practical limit generally allowed is one-quarter breaking strain, whereas in dealing with cast iron we allow one-sixth breaking strain as the safe working limit; what I maintain is, that in dealing with mild steel the safe working limit may safely, for similar reasons, be extended to one-third the breaking strain; and if this were agreed to, a ship constructed of mild steel need not be made any thicker in its scantlings than one having a breaking strength of 35 tons, such as I am sorry to find is now being advocated by shipbuilders. Regarding the remark made by my friend, Mr. Bramwell, I am ready to agree with him in principle to this extent: That if a steel could be produced of increased ultimate strength without in any way trespassing upon the quality of extra mild steel, of maintaining its ductility after tempering, and after punching or bending, that material would deserve the preference; but so long as the strength has to be preserved at the expense of ductility, I must maintain my objection to an advance, or rather a retrogression in that direction in shipbuilding. I may add one word of entire approval of the opinion put forward by Mr. Denny, that all plates ought to be tested at the works of the maker, in the most careful and rigorous manner possible, and not at their destination, and also that for riveting steel plates, steel rivets only should be used.

Mr. Benjamin Martell (member of Council). My lord, I was about rising just before Dr. Siemens rose, to make precisely the same remark which he made, as regards the loss of strength relative to the hardness of the steel. It is doubtless a matter of great importance to have the material of the greatest strength, but all our experiments have gone to show that the harder the steel the more it lost in strength in punching. That is a point we must not lose sight of. It is a matter of the highest importance that if we profess to have steel of a certain strength, that strength should be pretty well maintained after manipulation, either in punching, shearing, or working; and until some means can be found of not only obtaining a higher tensile strength in this material, but likewise that will enable it at the same time to be punched and sheared, and go through all its processes of manipulation without losing strength to the great amount of 25 or 30 per cent., it would be unwise to extend the limit which Lloyd's committee have adopted to any great extent. They adopted their limits after a large number of experiments had been made, and it was not found that you could with safety go much beyond that limit, to preserve the qualities necessary for ship-building purposes. With reference to Mr. Denny's very warm and rather strong remarks respecting the testing of steel at works, instead of in the ship-building yards, it must be borne in mind that Lloyd's committee, in adopting the rule they did, felt that they had very great responsibility cast upon them in accepting this material for ship-building purposes, and that they were compelled in accepting it, to lay down rules to guard themselves in undertaking this very great responsibility which should relieve them in the eyes of the country, and those who rely on their classification, from that responsibility which they considered ought to fall on the manufacturers and the ship-builders themselves. I can sincerely say that they have always taken into consideration every facility that might be afforded in carrying on work, if they could properly do it consistently with their responsibility to the ship-owners and underwriters, and those who intrust their interests to them; and if it could be clearly shown that they could be relieved from undue responsibility, and that they could insure that an article of uniform quality in every respect, and perfectly reliable, could be sent to the yards with confidence, I am sure that they would be quite ready to give the suggestion now made their very serious consideration. I may say that they have at present the question under consideration, and I am also sure from my knowledge of them and the manner in which they consider these things, that they would pay attention to every remark made with reference to it—that they will not be obstructive, but will only be guided by one desire, and that is to facilitate the ship-builder's interest, and the interest of everybody concerned, consistently with their responsibilities. But at the same time it is a matter of far too serious importance merely to take into consideration the interests of the ship-builders alone. There is no question that it is a very great inconvenience and a very great expense to the builders to have to test the material at the ship-yards. But the matter will have to be most thoroughly considered before the committee will relieve them from what they consider their just responsibility. I am sure they must have it laid before them in a very plain manner that the high character of this material is being maintained, and that the means proposed to be adopted for its test will be of such a character that it shall not deteriorate in any manner—which they fear, if we were to give up rigid tests, would be likely to occur. Whether it can be done at the manufacturers' works without undergoing the additional expense and inconvenience of doing it at the ship-building yards is matter for consideration, and I am quite sure that Lloyd's committee will take everything that has been said into their consideration with regard to it.

Mr. A. C. Kirk (member). My lord, I will commence at the latter end of Mr. Denny's paper, in this matter of testing, as it is a matter on which I, with all other ship-builders, feel very strongly, and I think this a matter in which we may fairly assume the character which our president has already given us, and constitute ourselves as a jury, and give a verdict; and I hope that every ship-builder and steel maker, and the other gentlemen here who are interested in it, will unite in contributing to that verdict on this most important subject. The case to be tried is very much this: A very worthy elderly gentleman, called Lloyd's, has hitherto been extremely kind and helped to bring up a very interesting young man called Steel, but lately there have been signs that he is attempting to strangle him. Now, that is the case that has got to be tried. It is such a singular case, that if I were counsel for the worthy gentleman, the only excuse I could make would be temporary mental aberration. In fact, it seems to me a most extraordinary case of how not to do it. After we have waited, as Mr. Denny has pointed out, for weeks and weeks, to get delivery of our steel plates from the works, just suppose, when our work is all carefully arranged to be taken up, the various parts in regular succession, that these plates come in just at the last moment, and are ready to fulfill that condition. They are tested by Lloyd's at the works; they are rejected; and they have to go back to the middle of England perhaps. The steel maker, not seeing them tested, disputes the whole thing. You see the endless time that is spent. You have the carriage of the plates back, but that is little matter; the chief thing is the loss of time. The steel maker gets it sent back, and he tests it, and he says it is all right. He probably gets a plate that is all right, and Lloyd's probably got a plate that was wrong. By the other plan testing is done at the works, as I am happy to say is done by the Liverpool underwriters. We have had ships built under the Liverpool underwriters; one built under the admiralty officers, which is going on now; and there is another which we have going on now for the Messrs. J. and A. Allan, built under their own inspector, and in all these cases the plates are tested at the works. In all these cases I think every plate has had a bending test taken from it, which can be done with the greatest ease at the works. I do not think we have had all through a single plate or angle iron condemned for working after it came to the works. I think that should relieve our good friends at Lloyd's from the idea of any undue responsibility whatever being thrown on their shoulders by this system of testing. Mr. Martell speaks of the expense coming on the ship-builders. That is only transitory. It will presently come on the ship-owner. I will now leave that subject.

We have heard a great deal about the testing of steel, but we have got on for a very long time with iron, which was never tested. With the best Yorkshire iron I have seldom had to reject less than 15 per cent., or sometimes double that, for giving way in the working, and I have little doubt that if our steel was not tested at all it would be, in fact, in a very short time, on all-fours with iron. It is a much superior article in itself. My argument is not that we should not test steel—far from it. Let us test steel. By testing steel and knowing exactly the quality of the article, we shall then be able to reduce the factor of safety, or the margin that we give to our structures to cover the defects of iron, considerably. I think that is a view that, now the manufacture of steel is established so far as it is, should begin to have a little attention. While I can agree with every word almost in Mr. Denny's paper, I think there is a little doubt about the question of its being dangerous to work steel at a black heat. Several things have cast some doubt upon it. I think I saw some specimens bearing on this in Mr. Parker's office, but I will pass that over without going further. As to the pitting that Mr. Denny referred to in the *Irawaddy*, we must not draw much of an argument from that, because so much depends on the water in which the plates were. Not long ago Mr. Laird, whom I see here, I think, built a ship for Dr. Livingstone, which went out to the Zambesi—fifteen or twenty years ago. That was built of steel, and that ship certainly pitted very fast, and there was a great deal of comment made on it, which was most unjust and improper. The fact is that the water of the Zambesi corroded all iron at the most abnormal rate. I merely mention this to show that we must be careful not to generalize too much. I will return to the question of testing, just to allude to the success which, so far as I have ever seen, has attended the practice in other departments of Lloyd's—the boiler department. They have hitherto tested at the works, and the practice has been most thoroughly successful. Now, gentlemen, a boiler is exposed to heavy strains, far heavier strains than a ship—in certain ways at any rate—and the consequences of failure are generally supposed to be more serious. If that can be tested at the works, surely a ship's plates can. In coming to Mr. West's paper—and, in fact, here Mr. Denny's and his overlap each other—my sympathies are entirely with having a stronger steel. Up to the present time we have driven our steel makers to exercise the utmost ingenuity to produce the nearest approach to wrought iron that ever their process will allow them to do. I think that is a very fair statement of the case. At first, as it was said, people were nervous about steel; but that nervousness was not at first, that was in the middle stage. Look at Mr. West's plates here—people were not nervous then. You have their plates about the same strength as those which are going to be put in for the chains of the Firth bridge, and these plates have not only done their full service, but they stand bending, and have a very high tensile strength, a half more than we generally use now, and these plates have been punched. After all that, and after their having answered the purpose for fifteen years, I do not know why people should be so very nervous about them. There are two ships sailing from the Thames here, built somewhere about the same time.

I cannot say exactly what kind of steel they are made of, because I have not had the good fortune that Mr. West had.

Mr. Henry H. West (member). Bessemer steel.

Mr. Kirk. No doubt they are very similar to the plates shown. I had the good fortune about three years ago to examine those ships very carefully both outside and inside, and I never saw better bottoms in a ship, and they are certainly very light. There is one of Mr. West's tests, however, with which I have no sympathy whatever, and that is the tempering test. Why the skin of a ship should be tried whether it can be hardened or not, I think it would require great ingenuity to answer. I never heard of a ship being made red-hot and stuck into the sea. I suppose that the tempering is to see whether it can be punched or not. The simple way, I should say, is to punch the stuff and try it, if that is all it is for. Hard steel might be punched, but no doubt it would be better if it was drilled. I dare say that the plates of the ship referred to might have been made thinner if they had been drilled, instead of being punched; but perhaps, in our transitional state, until the manipulation of steel is more generally understood, the tempering test may be beneficial as a transitional thing in the case of frames; but in the skin of a ship, where the plates never see the fire at all, except the garboard strake and a few odd plates elsewhere, it really seems to me perverse ingenuity to test them all in that way. Before I sit down I must make some slight allusion to Dr. Siemens' argument. As you see, my sympathies are entirely with Mr. Bramwell, and he stated the case very well. It is very difficult to take up Dr. Siemens' arguments, because there is a sort of strain of sophistry that runs through them which makes them difficult to handle. Dr. Siemens, if I take it rightly, argued that ultimately soft steel is very strong, because from its reduced section, when it ultimately broke, the strength per square inch was very high. If we could get the steel all strained to its reduced section before we put it into the ship, that argument would be very valuable. There is another point. It is not only tensile strength we want, but we want stiffness. Dr. Siemens seemed to think that with stiffness we should get brittleness, and if a ship were accidentally bent or buckled it would break. I would ask him to look at this piece of steel which is here. Here is a piece of hard steel, such as I say is very suitable for the skin of a ship. That has not broken, that has bent very well, and no steel in a ship would ever be asked to do as much work as that; at least, I should not like to be in the ship if it were.

Dr. Siemens. Has that been annealed?

Mr. West. It has not been annealed at all; it is just as it was taken out of the plate.

Mr. Kirk. I must say that I have felt for some time back, and I have expressed my opinion elsewhere, that it is a great pity that we should be losing the best and most valuable qualities of this splendid material by the limits of maximum strain. We may do it gradually; I do not say let us take rash steps. I believe, as a transitory step, Mr. West's proposition is extremely reasonable, but I certainly have an opinion that we shall get up perhaps to 35 or 40 tons to the square inch, and that before very long, and if the tools and treatment of the building-yard are not suited to that, the saving of weight would pay very well for a considerable revolution in our tools and method of working—drilling, for instance, and so on—might be looked in the face, in the light of the reduction in weight.

Dr. SIEMENS. Perhaps I may be allowed to make an observation in explanation. Mr. Kirk, in his remarks, rather accused me of sophistry, and he says that by using a harder steel he gets at any rate stiffness. Now, it would appear from this that I have failed entirely in my argument to show to Mr. Kirk that stiffness in an engineering structure does not depend on the ultimate breaking strain, but upon the elongation of the material within its elastic limit, and that that elongation is the same with mild as with hard steel; that, in short, if you limit your strains to 15 tons to the inch, the ship built of mild steel will be precisely as rigid as a ship built of steel bearing 60 or 70 tons to the inch.

Mr. WILLIAM PARKER. My lord, I would not have thought of addressing the meeting on this subject if my friend, Mr. Kirk, had not alluded to some experiments I have recently been making on plates intended for boiler-making purposes. It does occur to me that the severe treatment plates are subjected to, in bending and flanging them into the peculiar shapes required in marine boiler making, is a pretty good test of whether the material is fit for the purpose intended or not. There have been within the last twelve months no less than one hundred and sixty steamships in the mercantile marine fitted with boilers made of mild steel, which represents something like 3,000 tons of plates. About twelve months ago a great deal was said about steel plates and angles cracking in a mysterious manner, but strange to say, since the discussion of that subject at the meeting of the Iron and Steel Institute in May last, the mystery seems to have almost altogether disappeared; in fact out of the 3,000 tons of plates referred to, not one case of failure has been reported. These plates were all made in this country. Some three weeks ago a large quantity of plates made on the continent were delivered in this country for boiler-making and ship-building purposes; they appeared to be perfect in every respect. Specimens were taken from them, and they stood quite well all the mechanical tests required. About four hundred of these plates were intended for boiler-making; 25 per cent. of them were tested and found to have a tensile strength of from 27 to 29 tons per square inch. A strip was taken from every one of these plates, bent double cold in the usual way, without the least sign of a fracture. Some of these plates had to be flanged into tube plates, and every plate that was tried cracked, laminated, and fritted away at the edges under this treatment. This seemed to me to be rather remarkable, and led me to further inquire into the matter, and if possible ascertain the cause. It appeared quite plain that, whatever the cause, mechanical testing would not discover it. Pieces of the German plate were analyzed and compared with the analyses of steel manufactured in this country, which worked perfectly well under exactly the same conditions. This analysis was made by four different chemists, but they showed such a close approximation in the composition of the two materials, as to render impossible a solution of the difficulty by analytical comparison. The cause had to be looked for elsewhere, and that reminds me of Mr. Denny's remarks as to the brittleness of steel at different temperatures. I had from both the German and the English plates a number of specimens prepared, so that they could be tested under various degrees of temperature. Professor Kennedy, of the University College, kindly tested them in his machine with the following results: At a temperature of 70° F. the tenacity of both steels was practically 30 tons per square inch; at 450° the tenacity was increased to 37 tons; at 600° it fell to 33 tons; and at from 1,000° to 1,200°, or say a dull red heat, the tenacity, as naturally would be expected, fell to about 13 tons per square inch. It was also observed that although at a temperature of 450° the tenacity was increased about 23 per cent., its ductility was decreased over 33 per cent., which corroborates Mr. Denny's opinion that at black heats this material is very brittle. The results of all these tests were thus quite beside the mark, so far as the immediate object of the inquiry went; and in making further inquiries from the makers of the steel, I found they had never seen a marine boiler in their lives—they had no idea that these plates had to be heated, worked, and tortured in this manner, and therefore they had not left a sufficient margin at the ends of the plates after they left the rolls, to cut off the unsound parts. It was observed that the laminations were confined to one edge, and when some 18 inches of the unsound parts had been cut off the remainder of the plate flanged beautifully. I mention this case more particularly to show that although steel plates stand satisfactorily all the mechanical tests that are applied to them, it does not follow that they are in every respect satisfactory for the purpose intended; they have to undergo a still greater test, viz, bending, flanging, and working under various degrees of temperature. I am very glad to see that Mr. Denny has referred to riveting, because I think that subject, especially in steel structures has been very much neglected in boiler-making. Where heavy iron plates are used it has been the practice of the country to consider that the maximum strength of the joint is obtained when it is proportioned so that the sectional area of rivets to resist shearing is equal to the sectional area of the plate between the rivet holes. Now, in an iron joint the strength of the rivets to resist shearing will not probably be more than 18 or 19 tons per square inch, while the tensile strength of the plates will be 20 or 21 tons per square inch of section; but in a steel joint the strength of the plates is very much in excess of the strength of the rivets. Say the plates vary from 28 to 30 tons per square inch, whilst the shearing strength of the rivets will not be more than 19 to 20 tons per square inch; so that to obtain the maximum strength in a steel joint in addition to the plates being drilled, or rimed, or annealed, after punching, the area of rivets should be at least 25 per cent. in excess of the plate between the rivet holes, and in ship work, as Mr. Denny has stated, they would probably have to employ treble or even quadruple riveting. Referring to the subject of corrosion, I had an opportunity of inspecting one of the steel steamers referred to by Mr. Kirk about six months ago; she is now about thirteen years old, her plates were three-sixteenths inch thick, she had been in collision, and the lower part of the stern had to be taken out; this plate had never been painted inside from the time the vessel was launched; still it measures three-sixteenths inch yet, and can be seen at any time at the office of Lloyd's Register. A few days since I had an opportunity of inspecting two magnificent channel steamers built of steel for the London, Brighton and South Coast Railway Company, by Messrs. J. Elder & Co., at the beginning of 1878. The boilers of these vessels are made partly of steel, the shells are made entirely of steel, the combustion chamber plating and the furnaces are made of Yorkshire iron, and the tubes are of brass. They have been running two years, only changing the water at intervals of twenty-one days, so that excessive corrosion or pitting in one of these materials might have been expected from galvanic action or some other cause, but nothing of the kind was observed more than would be expected in iron boilers of the same age. I took advantage of the opportunity and inspected the hulls of these vessels, which are also free from corrosion.

Sir John Alleyne. My lord, I should like to be allowed to revert back to that part of the discussion where Dr. Siemens left it. Whether we have a high tensile strain or a low tensile strain, Dr. Siemens has himself given us, in the splendid furnace he has invented and taught us how to use, the means of making any quality of steel which customers ask for. Mr. Denny alludes to the delays that are caused in getting steel plates and so forth. This arises in a great measure from the testing. If, as in the splendid example set by Mr. Barnaby and the officials of the admiralty, we were allowed to have our tests at the works, all these things would be discovered during the process of manufacture; but the manufacturer is afraid to make too much, because he may have to send it all the way to Glasgow from the middle of England, and then to send it back again from Glasgow to the middle of England. Why will not Lloyd's and the other authorities do as the admiralty do—allow the plates to be inspected at the works? They have the hot test, the cold test, the hardening test, and the tensile-strain test; and there is a splendid set of apparatus for all kinds of tests, and we are not allowed to use it in those cases. An odd plate gets condemned, and it condemns the whole lot, and back it has to go from Glasgow. I agree with those gentlemen who have urged that the testing at the manufacturing works will prove to be a very great facility. Mr. Martell kindly and handsomely says that the matter is under consideration, and no doubt with the intelligence that Lloyd's always bring to bear on things of that sort, we shall have presently testing at the works. I am sure that this improvement is really due to Mr. Barnaby and those gentlemen who are employed with him, in the way that they facilitate work. They have an inspector there, and I believe the admiralty get their supplies rapidly and expeditously. I do not think they have the delays complained of by Mr. Denny and other speakers.

Now, I will only address myself to one short point, and that is as to having the low tests. I am not quite at liberty to mention it, because it has been mentioned in another institution of this kind, and may be considered second-handed, but perhaps you will excuse it. There were a number of tests made between steel and rolled beams for ships.* If you have a low limit of elasticity in steel, as you do when you insist on a low tensile strain, you bring iron up into competition. There were six rolled beams—rolled, as near as they possibly could be rolled, alike—for Mr. John to test, six made of iron and six made of steel, and for fear of mistake as to the quality, we got the blooms of this steel from Landore, and they were most excellent. The ultimate point of the elasticity of the steel was low, and the ductility was so great that the iron competed with it—the iron beam was within 3½ per cent. of the rigidity of the steel. When you can do that, I want to know what is the good of the steel? I think, myself, you are sacrificing some of its qualities in insisting on a low test. I do not press that, because I say that you gentlemen who use the material are the gentlemen to tell us manufacturers what to do, and we will do it; but we do ask you to put all the pressure you can upon Lloyd's and other departments which have not been mentioned, who insist on having the plates sent to the shipbuilders to be tested, putting them to no end of trouble and expense, and, in some cases, to have them sent to London. If this is to go on we shall next not be allowed to weigh it before we send it, and you will insist upon its being invoiced in London, and all manner of difficulties will arise from it. I think that is unreasonable, and although I do not like to use a strong word, an obstruction upon our manufacturing process. It is a delay that causes no end of mischief, and I do hope, with other gentlemen who have spoken, that this meeting will make its voice heard in the country, and put an end to such absurdities as we are suffering from at present.

Mr. John Corry (associate). My lord, as I anticipated, we have had a paper of very great ability from Mr. Denny. He has dealt with the subject in a very clever and very fair way indeed; but as I anticipated, although this paper has been ostensibly delivered to this Institution for general information, it is aimed a good deal at Lloyd's committee. As one of the members of that body, I am not at all sorry that we have

---

* Lloyd's at Butterley.—J. A.

had this paper, although it does not bring out any matter that we as a committee were not practically acquainted with. I think one of the most important facts brought out by Mr. Denny's paper is that riveted joints are not equal to the tensile strength of the steel plates they connect—that is, if we were to admit to very high tensile strength for our steel, great practical difficulties would arise in making the joints or butts proportionally strong. In the scale prepared by Lloyd's for the reduction from iron, it was considered that 20 per cent. represented the difference as far as we could then judge; and I think that the allowance of a minimum strength of 27 tons, as admitted, is a fair allowance considering the amount of loss in working. My own feeling in the matter is that we should not be too refined in objecting to plates even of higher tension than admitted, if the ductility were maintained; because, after all, I believe it might be possible to make plates up to 50 tons, and still retain an amount of ductility to which there could be no practical objection. But at the same time, as all steel-makers affirm, and as our experience leads us to believe, the harder the plate the more difficult it is to retain its ductility, and the more it is injured in working. If a practical difficulty arises in making the butts equal to this extra strength, I cannot see that any advantage would be gained. There is no doubt, from a ship-builder's point of view, there would be an immense advantage, and also from a manufacturer's point of view, in having the material delivered at the ship-builder's yards liable to no test except that which the ordinary process of working would subject the material to; and I am sure that the members of Lloyd's committee would be delighted if such an end could be obtained with the certainty of a result which we consider to be necessary. We all must know that the testing of steel involves an enormous amount of extra labor on our surveyors, as also does the correspondence with regard to it; but I have not heard any ship-builder or manufacturer suggest that the material, at the present time, is of such a nature and so perfect that it does not require to be tested. If you could manufacture steel like a piece of Low Moor iron, as it were, so that we could say it would stand within a fraction, a certain strain, and work up to a certain standard, that would be a state of perfection to which we would like to see it attain; but I do not think any manufacturer would pretend to say that he cannot make *bad* steel if there is a want of care; and even in the beautiful process of Dr. Siemens, the great advantage, I believe, is the facility which you have of testing the material while in process of manufacture. We know that good cookery requires a good cook, and very often good food is spoilt in the cooking. As Mr. Martell has pointed out, the whole question is under the careful consideration of Lloyd's committee, and will have their best attention; but there are other views than those expressed to-day, which I need scarcely refer to.

Mr. J. I. THORNYCROFT (associate). My lord, I would beg to make a few remarks upon this subject, because I feel that we are so much interested in having, if possible, with all deference to Dr. Siemens, a stronger material than we now have, and, if it is possible, that the ductility should be maintained. I think it is highly desirable that the tests should allow us to go to a higher point than say, 32 tons, which is allowed by the Liverpool underwiters. That appears to be the highest limit which is allowed by that important authority. I think it has been proved, and the discussion to-day shows that really one very great test in the behavior of steel is how it behaves in working, and it is amply proved in working, that even the hard steel will bear treatment which iron usually fails to undergo; and I know from my own observations that things that can scarcely be made in iron from the amount of work required on the material, are quite practicable to be made in steel as now delivered. What I am anxious to say is, that if it is possible to let us have a stronger material, pray do not let us have any hinderance put on the steel-makers, but if we can have it, let us have it. I, myself. have made structures in which the strength of the materials has been of the greatest importance, and I feel that I should like to urge this one point. From what I have seen in some accidental collisions of boats—I must not call them ships—it would appear that in accidents the material always comes out well, and where iron would have broken, the steel plates employed, which have been thus accidentally tested, always resisted well.

Mr. Hamilton. My lord, allow me to say that previous speakers have, I think, in objecting to stronger steel, made too much of the difficulty of strengthening the joints. This can be done in different ways at the outside strakes by making the liners extend across the flange of the frame, thus bringing other two rows of rivets into play, or it may be done by joggling the straps of the inside strakes over the leaf of the frame, or by increasing the distance between the frames. I think there is no great objection to the additional strength of steel to be made on this ground. I may say in corroboration of what Mr. Kirk has already said, that we have handled now between 3,000 and 4,000 tons of steel, all of which has been tested at the maker's works, with the exception of one or two plates, which, in their overzeal to give us good delivery they sent in without having tested and examined them. These plates are the only ones that have caused us delay and expense, and they have caused us very serious delay and expense, amounting to £50 a day, through the non-payment of installments brought about by those plates being found out through surface defects to be unsuitable, and having to be replaced at the last moment.

Mr. James Riley (associate). My lord and gentlemen, I am strongly reminded to-day of the last opportunity I had of speaking in this room. Mr. West has quoted the very text of my paper which I had the honor of reading here five years ago. The Landore Company, with which I was then connected, accepted the challenge which Mr. Barnaby put forth. The result of the efforts made by the Landore Company, and the company with which I am now connected, and others, is, that Mr. Denny and other gentlemen complain they cannot get deliveries. The demand has grown because of the great care we have taken in the production. Knowing how that success has been achieved, I must say that I feel a considerable amount of hesitation in giving way to the pressure which is being brought to bear upon us by some of our friends in this room. I feel more inclined to follow the lead of Dr. Siemens in this respect. There is no question, that we are anxious as manufacturers to do all that our friends would require of us. We have proved that in the past, but I would say that any departure from present tests should be very cautiously undertaken. It has not been noticed by the gentlemen who have spoken before, but in the very cases quoted to-day Mr. West had told us that of the two plates which were removed from the vessel he named one was cracked. Gentlemen, I think we have removed considerably from the position of doubt and anxiety, fear and trembling, I think, were the words, which existed five or six years ago. I am beginning to feel tolerably comfortable in my mind, because we are now in a safe region. If we depart from that region we shall not experience the same degree of comfort and certainty, and we shall not be able to please our friends as well as we are doing now. From all these points of view I would say, although I am not going to be obstructive, but will try in every way to meet you, be very cautious how again you depart from the position you have taken up. I wish particularly to refer to this matter of testing, and where it should be done. Mr. Denny, in his admirable paper, for which I thank him, has shown the results obtained from very large quantities of steel supplied to him. It is true that there have been some difficulties at times, and these difficulties have been enhanced because of the delays contingent upon the question of testing. A gentleman who has spoken rather seemed to raise the question that we wish to get rid of tests. I beg to disclaim altogether that proposition. We do not wish to get rid of testing. If Lloyd's, Liverpool, and the other societies, gave up the matter of testing, I individually would not, because I maintain that the reputation of all the firms engaged in the manufacture of this material depends upon the amount of testing that is done, and the care with which it is carried out, and therefore I disclaim altogether the thought that we wish to get rid of testing. I did intend to have made another remark, and that is as to the question of having a higher test. I think Mr. Denny has pointed out how this might be treated tentatively. Why not, as he has said, make the inside portions of a vessel of a higher or stronger class and keep the shell, the outside portion, of the same mild ductile material as that with which you are now being furnished? I think that the proposition is very well worthy of consideration, and it is perhaps the best way in which to treat the matter.

Mr. Hamilton. You will excuse me saying that, in paying the Star Company a compliment, as I meant to do, I unfortunately omitted to say that it was a pure accident that in this single instance two plates were sent in without being examined at the works.

Mr. Henry H. Laird (member of Council). My lord, I feel that this admirable paper of Mr. Denny's has been so fully discussed that it is hardly necessary for me to enter into it, and I do not think I can throw any light on any of the particular points. But as a ship-builder I should wish to express the thanks of this Institution to Mr. Denny for having put before us the results of his experiments, and his experience, so fully as he has done to-day. As a member of the firm which I think was among the first to make use of steel in constructing vessels of various kinds, I may say our experience has been equally satisfactory. We built a number of steel vessels so far back as 1858, which have been doing good work ever since, and in which we had very little, and in fact no trouble at all in obtaining material which was quite suitable. But in those days we resorted to the practice—a somewhat expensive one—of ordering every plate 3 inches longer than we wished to use, and we cut that piece off the end and tested it ourselves. By the system of tests now adopted by all steel-makers, namely, testing every plate at their works, which system I must add my approval to, that is rendered quite unnecessary. Practically all the steel-makers now do carry out the system of testing every plate, and I can only say I think that ought to be done in all cases, and at the works of the manufacturers. There is one point to which I would wish to refer, and that is as to the use of steel rivets. We have used steel rivets in every case where we have built vessels of steel, or used steel, except for the Admiralty, and we have never had any reason to repent doing so. I believe that steel rivets are now being generally used, and I am sure that very satisfactory results will be obtained from them if they are of a sufficiently mild quality, and great care is taken in the heating. With reference to the failures that Mr. Denny referred to in the steel, we have had very few—fewer I think, perhaps, than he seems to have experienced—and in every case the manufacturers of the steel have on investigation attributed it to some improper heating. We never had a single failure where the material has been worked cold in the condition in which it was delivered to us. With reference to the minimum strain that it may be desirable to fix for steel in the future, I should be rather disposed to say that we should go as high as it is possible without altering materially the present system of working; that is to say, we should go to as high a strain as we can safely do, without annealing after punching and riming, because in our experience, when you have come to a point of hardness at which you require to anneal every plate, it becomes very tedious and somewhat risky. With regard to durability as connected with corrosion, in 1858 we built a vessel, called the *Deerhound*, of Bessemer steel. She was only about three-sixteenths of an inch thick, and up to a year or two ago she was safely at work in good order, and I believe is so still. The *Isabella*, a vessel we built in 1876 for the London and

Northwestern Railway Company, has recently been in dock and stripped for examination in order to ascertain this very question, and she was found to be in admirable order, no corrosion either inside or outside to speak of, and not so much as one might have expected in an ordinary iron-bottomed ship. As to the practical advantage of this very superior material in ships' bottoms, I may mention the case of a vessel called the *Storm Cock*, which was built of Siemens-Martin steel, made by the Landore Company. When employed on the coast of Ireland alongside a ship which was stranded, she bumped very heavily on the end of a winch or something of that kind, and an indentation was made in her bottom very much resembling a large dish-cover, about 16 inches in diameter, and 5 or 6 inches in depth. The effect was, that the steel plate which was indented in this sudden and severe way by a single blow, simply split for a short length along the edge of one of the supporting frames, and the leak was so slight that they were able to take the vessel into harbor and repair it by putting a patch on it. I think that the opinion of all experts who have seen that plate is, that had it been iron even of a superior quality, the end of the winch, or whatever she struck on, would simply have punched a hole right through her. This confirms, I think, the case of the *Rotomahana*, and is the only practical experience that has come under our notice. I think we have to thank Mr. Denny very much for giving us the opportunity of this discussion, and so much valuable information as these tables contain.

Mr. THOMAS ADAMS (member). All the experiments that are recorded in these valuable papers, especially Mr. Denny's, are fraught with useful information from beginning to end. He depends entirely, as also do all the speakers who have engaged in the discussion, upon the tensile strain as the measure of their knowledge of steel. Now, that can only be one element in the calculation of a structure composed of a number of parts of steel, and although it is one of the principal elements, yet you build up a structure which, if you depend on that single element, will lead you astray, deceive and disappoint you. I have had the pleasure of seeing a number of experiments made upon steel by the chief engineer of the Board of Trade and his assistants, which will be published in the course of six weeks in a blue book, and certainly they are the most important that have ever yet been placed before the public on several grounds. The experiments have not been made on the tensile strength only, although that has not been neglected, but the structure itself, representing the ship's side and the boiler, has been constructed and in that state destroyed. Mr. Kirk asked us for a relation between the best Yorkshire iron and steel. I have not all these experiments in my memory, but I have that one and I can tell him. The best Yorkshire iron is Low Moor, and in those tests to which I have been a witness, the best steel tested by the Board of Trade has been manufactured by the Steel Company of Scotland, and the proportion between Low Moor plate and the Steel Company of Scotland's plate is in the proportion of 12 to 20.05. For example, if a given structure built up of half-inch Low Moor iron would be destroyed by 1,200 pounds to the square inch, and a structure built up of the Steel Company of Scotland's steel would be destroyed by 2,050 pounds to the square inch, all things being the same. That is the proportion between Low Moor iron and the Steel Company of Scotland's steel. I do not think I have anything else to say. I have nothing to say against Lloyd's.

The PRESIDENT. I may express the hope that we shall not be involved in what I see the Times of to-day calls "an oratorical deluge," as our time is fast drawing to a close.

Mr. DUNCAN (associate). I am very much obliged to Mr. Adams for saying he does not find any fault with Lloyd's. We have heard Lloyd's described as an old gentleman, and I think it as well that they should have some experience, and not altogether be young men. All that I have heard to-day shows, and I think that every person present who has listened to this discussion must feel, that those who have to certify that a structure made up of a certain amount of material is fit to do certain work, require at least to exercise as much care as they can in ascertaining the quality of the material of which that structure is composed. Now, I think that that is all that Lloyd's desire to do. I am here to testify that Lloyd's as a body are very desirous indeed to do everything in their power to further and to assist in the construction of a mercantile marine of the best description, and made of the best material, and got up at the least possible expense. They are not prepared to stand in any respect in the way of any improvements that can be made in any direction; but when a gentleman here has stated that two plates which were not tested cost them £50 a day when they were brought in, it appears to me that is a very strong argument indeed that the testing should not certainly be less than it is at this time. I think that we are in a transitory state just now; steel will be improved, and will no doubt continue to improve; but it is perfectly clear that steel has not got to the state when it can be made so entirely homogeneous as to be perfectly depended upon, so that every plate shall be the same. I think it is very necessary that the responsibility of making good steel should lie upon the maker, and that he should run the risk of his steel being so good that when it comes to the yard to be used it will pass the ordinary test required by Lloyd's for the purpose of going into the ship. It appears to me that if we were to take away at the present time that responsibility, and were to say that where they are making such quantities as they are doing now, working night and day continuously in their works, and that we should be required to stamp on the plate, and the maker to have nothing more to do with it, whether it was good or bad, the consequence of that at this time would be very serious and disastrous. I am quite prepared to say that Lloyd's are considering everything that is being put before them, and I am sure the moment that Lloyd's are satisfied that they can safely take off any of the checks that they have at this time they will be very ready to do it.

Mr. J. INGLIS, Jr. (member of Council). I think it must be very gratifying to Mr. Denny that so many eminent men are of his opinion as to the system of testing steel adopted by Lloyd's. I can only say that I have found it an intolerable nuisance, without any redeeming feature; and I have heard nothing from the other side—the gentlemen representing Lloyd's here—in favor of the present system, or anything to show that it is the most efficient, or that there is anything to insure a better quality of steel than would be insured by testing at the works. Mr. Martell has said that they had adopted this plan so that they might avoid a certain responsibility. I never understood that it was the object of Lloyd's to avoid responsibility. They cannot do it, because they take it upon themselves to survey the ships. They survey the material of which they are constructed, and the workmanship which is put into them, and we learn from Mr. John's paper that they are not indisposed to take the initiative in design. After they do this, although they do not relieve the ship-owner from responsibility, they cannot avoid having a certain responsibility themselves.

Mr. MARTELL. Undue responsibility.

Mr. INGLIS. Mr. Corry assumed that the desire on the part of those who wished steel tested at the works was to avoid testing altogether. I think Mr. Riley has quite sufficiently replied to that.

Mr. CORRY. I certainly did not say so. No one would advocate not testing the steel.

Mr. INGLIS. Then I have misunderstood Mr. Corry, as I thought he said it would be an advantage to the ship-builder to do away with testing. We certainly wish that tests should be made as rigid as necessary to insure a good quality. It is the locality at which the tests are made that we wish to have changed, and before this subject passes from our consideration, perhaps some member of Lloyd's will give us a good reason why the present system, which only tests about 2 per cent. of the material, should be retained, and the system which is advocated by the writer of this paper should be rejected.

Mr. JAMES SCOTT (member). My lord and gentlemen, I have only one quostion to ask, by way of a summary of the discussion. I think after Mr. Denny's and Mr. West's papers have been so fully discussed, that the discussion resolves itself into one question: Why is it that this superior material, admittedly superior material, should be subjected to so many searching tests? Why have we so many good vessels built of iron, an admittedly inferior material, which have never been subjected to those tests that steel is now undergoing? I think that any iron ship-builder will agree with me that the tests which this steel has to go through, in the manipulation of the different plates, will be sufficient to bring out any bad parts, or any part of the material of the plate which is not equal throughout. As Mr. Parker remarked, he found, in some plates he analyzed, that by cutting off certain parts from the edge, or all round the plate, he got into good material; I can testify to this in iron as bringing out the same thing. I made those admiralty tests for the purpose of reading a paper before this Institution in 1876, "On tested iron and ships," and in the testing of iron I found the exact results which Mr. Parker has found in steel, that the further he got into the plate the better the material. This arises simply from the cooling, and not from irregularity in the manufacture of the plates, the center of the plate being the last part to cool; the edges being the first to cool are consequently more brittle; as you get into the center of the plate, the material is increased in value. I think, after all the careful tests which the manufacturer requires to make to satisfy the public, or those that he supplies with the material, that his material will be good when passing into the ship-yard; and the tests it has there to go through will be quite sufficient to turn out what is bad. The punching, shearing, and bending of different plates in the structure of the vessel—I am speaking entirely of ships in the present case—will be sufficient to bring out the bad material. The punching of this steel, it being so much thinner than iron for similar purpose, and the pressure of the punch going through the plate, if there is any defect in the ductility, it will at once break out at the rivet-holes, and crack through the edges, and the butts will show in rolling where the defects are. I am sure that we are all very much indebted to Mr. Denny and Mr. West for their papers.

Mr. Adams. I will answer the gentleman's question in half a minute. It is a valuable answer to engineers and ship-builders, it communicates fresh and advanced knowledge. The gentleman asked what was the reason why so many experiments were made on this material.

The President. If you have risen to explain, Mr. Adams, we shall be very happy to hear you, but if you rise to answer anything that has been said, you cannot do it, and I must ask Mr. Denny now to reply.

Mr. Laird. I beg your lordship's pardon, I merely wish to make a correction. I said we had used steel rivets in all works we did, except for the admiralty, but I omitted to mention that in the *Seahorse* now building for them, they have approved the use of steel, and we are using it with very satisfactory results both to them and to ourselves.

Mr. William Denny (member of Council). My lord, I shall be very brief in my remarks in reply to the criticisms which have been made on my paper, and one reason for this brevity is that Lloyd's have made really no defense. They have not advanced reasons to show that the superior testing which can be done at the works should not be accepted instead of the inferior testing which is done at present, and they have not found from outside one single element of support. This meeting, so far as the general feeling has gone, has, I think, been in favor of my views. I have a very great respect for Mr. Corry and Mr. Duncan.

They are both men I hold in very high esteem, but I think they should explain why Lloyd's society can blow both hot and cold, and can at the same time have testing at the works for boilers and in the yards for ships. Dr. Siemens has, I think, mistaken me. I did not recommend that annealing should be abolished. I recommended that instead of it riming should be used, where plates were so thick that they would be injured in the punching. Regarding Dr. Siemens's other remarks, it seems to me that, if the limit of the tensile strength is not to be some indication to us of the rigidity of the material, we might almost return to iron, and would thus do away with one of the strongest arguments in favor of the use of steel. With regard to what Mr. Scott has said, I am sorry I cannot agree with him. I am no advocate for reducing the tests or their severity, but for increasing them, and for having the steel thoroughly tested. We are now carrying out a system of testing for unclassed work at the steel works, and taking care that the testing is watched very carefully by a representative in whom we have confidence. I did not intend to mention Mr. Riley's name with regard to deliveries, but I do not think the delay in them arose so much from the care in making the steel. Mr. Riley's work is too well organized for that to interfere with the produce. Perhaps Mr. Riley undertook more work than he could turn out in a given time. As to the steel test limits to which Mr. Riley has referred, I would remind him of this, that he himself has worked to Liverpool limits, and, I believe, with perfect satisfaction. I do not suppose that he intends to blame the steel so tested, and say that it is untrustworthy. From all I have heard of it, it was very far from that.

The PRESIDENT. I would ask you, Mr. West, in your reply to be as short as possible.

Mr. HENRY H. WEST (member). My lord, I will be as short as I possibly can. Dr. Siemens argues that the elongation of 30-ton steel and of 50-ton steel is the same up to a strain of 15 tons to the square inch, and, consequently, that where working strains are not intended to exceed 15 tons per inch, 30-ton steel is as good as 50-ton steel. Put shortly, I think the doctor's argument amounts to this: that a factor of safety of two is as good as a factor of safety of three, a position which I think few of us are prepared to admit. Then with reference to Mr. Riley's point, that we are now in a safe region at 26 tons, I thoroughly agree with him; but we cannot get much reduction of weight out of that. Scantlings cannot be reduced on 26-ton steel. But I say we are in a safe region when we go beyond 26 tons; we are in a safe region when we go beyond 30 tons. I hold in my hand, not one, two, three or a dozen, but scores of tests all over 30, and rising as high as 35.7 tons per square inch, of Siemen's-Martin steel, that has given us perfect satisfaction in every respect. Mr. Riley also referred to the one plate that was cracked in the vessel I quoted. It was cracked by a blow or collision; but as far as that is concerned, we must not forget that this is steel with .565 per cent. of carbon in it, and of a tensile strength of 44 tons per square inch. At present I am not advocating any such thing. I am content to ask a minimum of 30 tons to the square inch; and I am glad to see that Dr. Siemens in his remarks quotes this very tenacity as his example of strong and yet properly ductile material.

The PRESIDENT. I am very sorry, as this subject is one of very great importance, that I should be obliged to interpose at all to check the progress of the discussion. I can only now say that I think we must all have felt that we have had a very interesting morning, and have devoted that morning to the consideration of two of the most important subjects connected with ship construction of the present day. I mean the question of the cellular construction of ships, and the introduction of steel in ship-building. I cannot close this discussion without expressing the satisfaction with which I have heard the discussion, thinking as I do, that it affords a practical illustration of the great value of this Institution in illustrating the results of experience and in extending information. I cannot refrain also from expressing the satisfaction with which I heard the reply of Mr. Martell to what appeared to me to be the very natural observations of Mr. Denny with regard to the present mode of testing plating materials in the yard. Mr. Martell met that complaint in a spirit I think highly creditable to Lloyd's; and I must express my hope that Lloyd's will act in that spirit, and so far as there is any ground of complaint, that ground of complaint will be removed. There is one more paper which I think must be taken as read, as nobody is here to read it.

TWENTY MINUTES ON THE INCREASED USE OF STEEL IN SHIP-BUILDING AND MARINE ENGINEERING.

By John R. Ravenhill, Esq., *Member of Council.*

[Read at the twenty-second session of the Institution of Naval Architects, April 6, 1881; the Right Hon. the Earl of Ravensworth, president, in the chair.]

During the recent visit of your deputation to Glasgow at the opening of the Naval and Marine Engineering Exhibition, they found a general feeling to prevail amongst the engineers and iron ship-builders, that the present use of steel, both for ships and boilers, was only limited by the existing powers of production, and additional plant was being (and continues to be) prepared with the object of meeting the increased demand. Believing, therefore, that the subject possesses great interest, I do not hesitate to bring it prominently under your notice.

Steel as a material for the hulls of moderate-sized vessels (although of a very different description to that now in use) was successfully adopted in the commercial marine in the year 1859. The *Jason*, of 452 tons burden O. M., was built by Messrs. Samuda Brothers, for service in the Black Sea, and in 1860 the well-known Dover Mail Packets were constructed for the London, Chatham and Dover Railway Company, of the following dimensions:

TABLE I.

Name of vessel.	Built in.	Name of builder.	Name of engineers.	Length between perpendiculars.	Breadth.		Depth amidships, extreme.		Burthen in tons, O. M.	Diameter of cylinders.	Length of stroke.		Horse-power, nominal.	Description of engines.	Speed on trial, in knots.
				Ft.	*Ft.*	*In.*	*Ft.*	*In.*		*In.*	*Ft.*	*In.*			
Samphire	1860	Money Wigram & Sons	Ravenhill, Salkeld & Co.	187	24	10	12	9	$566\frac{50}{94}$	50	3	9	160	Inclined oscillating	16.47
Maid of Kent	1860	Samuda Bros	Boulton & Watt	187	24	10	12	9	$566\frac{50}{94}$	......	......		160	Inclined trunk	......
Scud	1861	......do	......do	218	26	0	14	0	$757\frac{42}{94}$	......	......		240	Inclined trunk	......
Foam	1861	......do	Ravenhill, Salkeld & Co.	218	26	0	14	0	$757\frac{42}{94}$	60	4	6	240	Inclined oscillating	16.6
Petrel	1861	Money Wigram & Sons	......do	218	26	0	14	0	$756\frac{42}{94}$	60	4	6	240	Inclined oscillating	16.5

NOTE.—Of the above five vessels, the *Scud*, *Foam*, and *Petrel* proved to be inconveniently long for their service in Calais Harbor, and were disposed of to other parties. The *Samphire* and *Maid of Kent* are still running on the station, the latter having been fitted some years ago with *new engines* (inclined oscillating) by the same firm as those who supplied them to the *Samphire*.

The specifications to which they were built have been handed to me by Messrs. Samuda Brothers, and the particulars will be found in Appendix A.

Steel for the construction of marine boilers was first used by the admiralty in 1857, the plates for them being manufactured by Messrs. Shortridge, Howell & Jessop, but the results were far from satisfactory.

Steel boilers were about the same time introduced into the commercial marine, but with very conflicting results, although it is right, perhaps, to say that there are land boilers now working at high pressure that were made of steel under the Bessemer process, about the same date, which have given and are giving every satisfaction. As regards the above-named steamers, they fully justified the anticipations of those who advised their owners to adopt a then quite new material, and no vessel could have undergone a severer test as regards strength of material than the *Samphire* did within a very short time of her being afloat; but the great cost of the production of the material militated against its becoming more generally introduced, notwithstanding the successful results obtained. The shafting on board the *Samphire* was made of puddled steel by Messrs. Thomas Firth & Son, the diameter of shaft necks being 10 inches. The improvements introduced since that date in the Bessemer process, coupled with the introduction of the Siemens-Martin principle, has entirely changed the aspect as regards the future use of steel plates.

They were first used by the admiralty for inboard work on board the *Bellerophon* in 1863, and formed the subject of a paper by Mr. Barnaby at this Institution in 1875, when he threw down a challenge to all those engaged in the manufacture of steel to provide him with a better material to work with; and the issue has been the successful results attained by the *Iris*, full particulars of which vessel in her steam trials have been brought under your notice at past meetings of the Institution, and you will remember her hull, as also the shells of her boilers, were made of Landore steel; and one officer had *alone* inspected the manufacture of 75,549 plates, sheets, and bars up to the 19th November last, only some few failures having occurred subsequently in their working.

Crank axles of the same description of puddled steel, by the same makers previously alluded to as having supplied the shafts for the *Samphire*, gave every satisfaction on board many vessels from my own personal experience, but they were then only in the position to manufacture them up to a comparatively small size for marine work, and the sad disappointment that attended the fitting of three large crank shafts on board some well-known mail packets that were supplied by a celebrated foreign establishment, together with failure in one or two other instances, retarded the further introduction of them on board steamers, but great progress has since been made in the material used for shafting.

Whitworth's fluid pressed steel for propeller shafting is well known, and his house has lately been engaged in making crank shafts, the plan adopted being as follows: The hollow crank pin is cast in one piece, with the blades; each piece of the body of the shaft is then screwed securely into its respective blade, with a key carefully fitted as an additional security, and this plan has found favor with some very eminent engineering firms, and it has been used by the admiralty.

On the other hand, Messrs. Vickers & Co., of Sheffield, have done a good deal in cast-steel crank shafts, but having regard to the old meaning of the word cast steel, the words malleable cast steel would, perhaps, be a more correct definition, as they all pass under the forge hammer after leaving the foundry. From personal inspection of a large crank shaft, having a coupling on the end of about 3 feet 6 inches in diameter, I can state that over the whole of this large surface, as also of all the surfaces of its blades and crank pin, the metal showed a striking similarity of color and uniformity of appearance, and the surfaces were clean and bright as a looking-glass; very different, as regards the inside portions of the crank, from the large crank shafts before alluded to, which showed a very crystalline appearance at their center. They have forged such shafts, in some instances, in one solid piece; in other cases they have adopted the plan largely followed in the North by marine engineers, in building up large wrought iron crank shafts. For liners of high pressure cylinders in compound engines, Whitworth's fluid-pressed steel is now in universal use by the admiralty, as also for screw propeller shafting, and as much as 36 per cent. in weight has been saved by its introduction. In the case of the *Inflexible*, it effected a saving in weight in the propeller shafting of, say, 34 tons, and had it been adopted for the crank shafts, a further saving of about 25 per cent. in their weight would also have been effected. Valuable as this material has proved to be, it has only been introduced as yet to a small extent in the commercial marine, but in the gigantic engines of the *City of Rome*, of the Inman Line, the built-up three-throw crank shaft and the whole of the propeller shafts are made of fluid-pressed steel.

Messrs. Vickers & Co., of Sheffield, were the first firm in this country to cast steel bells, and about eleven years ago they turned their attention to the production of cast-steel blades for propellers. The *Iron Duke*, armor-plated, of 6,010 (3,787) tons, and 4,270 twin screw (800) horse power, was one of the first vessels to which they were applied, and they have given during successive commissions the most perfect satisfaction, and are still in good condition.

A large number of our commercial steamers have also been successfully fitted with propellers of this material, more especially in the transatlantic service, where they have been found to be greatly superior to those of cast iron previously in use; but such is the severity of the work done, that at the end of about three years the blades become so reduced in thickness that they require to be replaced. The engines of the *Britannic* average about a total of 133,961,220 revolutions per voyage between Queenstown and New York. This same firm have also supplied some steel liners for cylinders for the commercial marine.

The present vast and increasing use of steel is really startling. The number and tonnage of steel vessels, steam and sailing, classed in Lloyd's Register during the years 1878, 1879, and 1880 are as under:

TABLE II.

Years.	Steam.		Sailing.	
	No. of Vessels.	Tons.	No. of Vessels.	Tons.
1878	5	2,929	None.	....
1879	6	12,473	1	1,700
1880	17	27,815	1	1,245

The number and tonnage of steam vessels, which, from the information in possession of their office made up to the 31st December last, appeared to be in course of construction (for they do not all come under their survey), were thirty-four steam vessels 111,467 tons, two sailing vessels 1,760 tons; as to which tonnage the author may mention that the Orient Company, the Cunard Company, the Peninsular Company, the Union Steamship Company, and others, are all building vessels of steel. As regards boilers, in the spring of 1878, only one steel boiler on board a steamer had come under the notice of Lloyd's Registry since the introduction of mild steel. From that date the number of steamships fitted with boilers, either wholly or partially made of steel, by returns also up to 31st December last, were as follows:

TABLE III.

Date.	No. of steam vessels.	No. of tons of steel worked up.
Between 1st May, 1878, and 30th April, 1879	120	about 3,000
Between 1st May, 1879, and 30th April, 1880	160	about 4,000
Between 1st May and 31st December, 1880	250	about 7,500
Total	530	" 14,500

NOTE.—Between 1st January and 31st March, 1881, thirty more vessels have been fitted, and an additional 2,500 tons worked up.

When it is remembered that these figures date back barely for two and three-fourths years they become very significant, and lead to the consideration whether the adoption of steel for marine boilers at no very distant date will not become general, for the use of steel for the shells of boilers made for the navy has become general since the adoption of the material for the boilers of the *Iris* five years ago. The greater working pressure sanctioned by all the authorities on boilers constructed of it, and the price at which it can now be purchased, compared with that of Yorkshire iron, must operate greatly in its favor, and although B. B. boiler plates show no deterioration in their quality, as evinced by the tests in the following table, the days for iron plates in marine boilers appear to be numbered:

TABLE IV.

Results of testing of Best Best tiger crown boiler plates, by Messrs. Kirkaldy, April, 1880.

[Plates manufactured for the admiralty.]

Description of iron.	Breadth.	Thickness.	Area.	Breaking strain.	Equivalent per square inch.	Elongation. in 6 inches.	Forge tests deg. bent. Cold.	Forge tests deg. bent. Hot.	Remarks.
No. 1 test:				t. c. q. lb.	t. c. q. lb.				
$\frac{5}{8}$ lengthways of grain.	1. 5	. 64	. 960	22 10 0 0	23 8 3 0	$\frac{15}{16}''$	$\frac{34^\circ}{32}$	$\frac{180^\circ}{180}$	Appearance of fracture fibrous.
$\frac{5}{8}$ crossways of grain.	1. 5	. 65	. 975	22 5 0 0	22 16 3 0	$\frac{3}{8}''$	$\frac{24^\circ}{22}$	$\frac{180^\circ}{180}$	40 per cent. of granular iron, fine grain.
No. 2 test:									
$\frac{5}{8}$ lengthways of grain.	1. 5	. 64	. 960	23 5 0 0	24 4 1 0	$\frac{9}{16}''$	$\frac{38^\circ}{36}$	$\frac{180^\circ}{180}$	Fibrous.
$\frac{5}{8}$ crossways of grain.	1. 5	. 645	. 967	20 5 0 0	20 18 3 0	$\frac{5}{16}$	$\frac{26^\circ}{22}$	$\frac{180^\circ}{180}$	Do.

The tests required by the admiralty are as under:

Tensile strain per square inch of sectional area, 21 tons *lengthways*, 18 tons crossways of the grain.

Forge tests for $\frac{5}{8}$ inch plates $\left\{ \begin{matrix} 27\frac{1}{2}^\circ \text{ cold} \\ 150^\circ \text{ hot} \end{matrix} \right\}$ *lengthways*, $\left\{ \begin{matrix} 12\frac{1}{2}^\circ \text{ cold} \\ 100^\circ \text{ hot} \end{matrix} \right\}$ crossways of the grain.

It must be remembered that the new material had to encounter strong prejudices, on account of the peculiar tearing of some of the plates whilst being worked into place, in several of the earlier cases. Much was also said during the first twelve months after its introduction into the boiler shops about the peculiar characteristics connected with it that working experiences produced, but local heating or other improper treatment had much to answer for, and as workmen have gained experience in its manipulation, the apparent difficulties in working it have to a very large extent, if not wholly, disappeared, and at one of the large marine factories your deputation saw boilers being constructed 16 feet 9 inches diameter to carry a working pressure of 90 pounds on the square inch.

Availing themselves of an invitation from Mr. Riley, the manager of the Steel Company of Scotland, the deputation visited those works, and on passing through the rolling-mills and the forge, they were shown steam-hammer piston-rods of 7 inch diameter, that had had their ends welded together after fracture from working, and were told that such repairs had proved to be a success, and also that no difficulty was experienced in efficiently welding together any width of boiler or ship plates. Their attention was next directed to the foundry, where steel castings are now being extensively produced under the same system as that practiced at the Terre-Noire works in France, to which establishment and to the rapid strides made in the production of solid steel castings, the attention of engineers and ship-builders was directed at the annual meeting of the Iron and Steel Institution, held in London in 1877.

M. Ferdinand Gautier, of Paris, in his paper on this subject, claimed for M. Euvert, the skillful director of the company, the credit of the first practical application of producing solid steel castings without blow-holes, and to whose genius and perseverance he attributed the discovery of the process. In his paper (see the Journal of the Iron and Steel Institute for 1877, vol. I) you will find a lucid description of the process, by which "the manufacture of steel without blow-holes has been perfected, by using a silicide of manganese and iron, which gives to the product remarkable qualities." He further stated that, "the very interesting fact that cast metal may have a higher density than forged and rolled metal had not been before pointed out, but that it had been ascertained at Terre-Noire that this density varied from 7.8 to 7.9, while that rolled steel never went beyond 7.81; from which he argued that a cast steel may be more dense than a hammered one, and that its strength may also be superior." His experience was based on the results of more than 500 tests of cast metal of three different qualities—hard steel for projectiles, strong soft steel, and very soft steel, and the lowest result of the latter showed a tensile strength of 33.2 tons per square inch.

Pistons of considerable diameter for engines in the Royal Navy, a three-throw crank shaft with necks 5 inch diameter, with a length of throw of 7¾ inches, making a stroke of 15½ inches, propellers, anchors, stop and safety nozzles, wheel gearings of all kinds up to great weight (12 tons being the heaviest casting yet recorded by them), and an immense number of small castings, many of them of a very complicated nature, to be subjected to heavy hydraulic pressures, together with others for ship requirements and locomotive and railway work, all in process of construction, tended to point to a new era in the foundry. (See Appendix B.) They were also informed that such castings have a tensile strength of about 30 to 34 tons, with a fair amount of ductility, and can be set, or bent, or even forged, if needful, and Table V gives you the results of four transverse tests of rough cast steel bars unannealed.

TABLE V.

Rough cast bars, 1 inch square. Supports, 2 feet apart. Load applied at middle.

No.	Load in pounds at first set.	Breaking load in pounds.
1	2284.8	2777.6
2	2032.7	2688.0
3	2018.0	2934.4
4	2032.7	2688.0

But the company does not send out any castings without their being annealed, and the value of this process is strikingly exemplified in Table VI, which shows the results of experiments on rough bars annealed, and annealed and cooled in oil, and on bars planed on all sides; in these latter, therefore, there was no skin.

NOTE.—The charge was of soft metal bars, one inch square. Supports, two feet apart. Load in the middle.

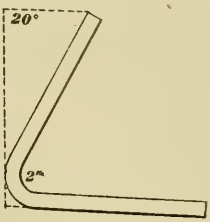
TABLE VI.

Rough bars annealed.	Rough bars annealed and cooled in oil.
Mean of nine experiments. Load 2,262 pounds at first set. Load 4,726 pounds at fracture.	Mean of five experiments. Load 2,531 pounds at first set. Load 5,667 pounds at fracture.

Plain bar annealed.

Load in pounds.	Deflection.	Set.
1, 334	0. 26″	0. 03
1, 680	0. 56	0. 30
2, 016	1. 46	1. 20
2, 173	2. 72	2. 40
2, 464	3. 62	3. 22

At this stage the lever of the machine was pumped up to the level, and on the load being again applied, the bar sunk between the supports.

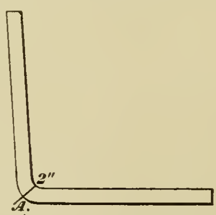


It was bent through about 110° and not broken.
Including angle = 70°.

Planed bar annealed and cooled in oil.

Load in pounds.	Deflection.	Set.
1, 680	0. 30	0. 10
2, 016	0. 55	0. 19
2, 240	1. 04	0. 64
2, 509	1. 62	1. 18
2, 688	2. 08	1. 62
2, 845	2. 6	2. 18
3, 024	....	....

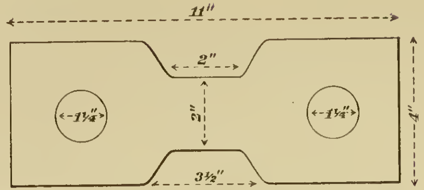
Sunk rapidly when last load was put on, continued bending till first sign of fracture was observed; then removed load. Found that it had been bent through 90°. Fracture at A.



As a comparison with the above I follow on with the results of some experiments at which I was present some years ago in one of Her Majesty's dockyards. The series marked A, were of the same quality of metal which was then in use by Ravenhill, Salkeld & Co.

TABLE VII.

A statement of the tensile test of cast iron, being pieces cut out of steam-stop nozzles formerly on marine boilers. The whole of the pieces cut out of the valve boxes were of the form sketched, but varied in thickness.



Distinguishing mark of iron tested.		Breaking strain, in pounds.	Dimensions of pieces broken.	Area of section broken, in square inches.	Breaking strain per square inch, in pounds.	Remarks.
A	1	24, 864	2 by $\frac{47}{64}$=	1. 468	16, 936	Iron light grey, close and fine.
	2	24, 080	2 by $\frac{44}{64}$=	1. 375	17, 512	
	3	23, 520	2 by $\frac{44}{64}$=	1. 375	17, 105	
					51, 553	
					Mean 17, 184. 33 = 7. 67 tons.	
B	1	26, 320	2 by $\frac{58}{64}$=	1. 812	14, 525	Iron dark, coarse, and open.
	2	26, 600	2 by $\frac{54}{64}$=	1. 6874	15, 763	
	3	25, 200	2 by $\frac{51}{64}$=	....	15, 809	
					Mean 15, 365. 33 = 6. 86 tons.	
C	1	28, 840	2 by $\frac{58}{64}$=	1. 812	15, 916	Iron lighter, finer, and closer than B; but darker, &c., than A.
	2	28, 280	2 by $\frac{54}{64}$=	1. 6874	16, 759	
	3	29, 680	2 by $\frac{52}{64}$=	1. 6	18, 264	
					Mean 16, 979. 66 = 7. 53 tons.	

TABLE, VIII.

A statement of the transverse test of cast iron taken from the before-named steam stop-valve boxes and melted separately, and run into bars 2 feet 3 inches long by 1 inch square.

Distinguishing mark of iron tested.		Breaking strain, in pounds.	Remarks.
A	1	1, 398	Iron light grey, close, and hard.
	2	1, 506	
	3	1, 524	
		4, 428	
		Mean=1, 476	
B	1	1, 702	Iron darker, softer, and not quite so close as A.
	2	1, 667	
	3	1, 639	
		Mean 1, 669. 33	
C	1	1, 340	Iron nearly the same as A.
	2	1, 282	
	3	1, 407	
		Mean 1, 346	

The following particulars, showing a comparison in the weights of cast iron and cast steel per ton, is therefore worthy of attention, and you have to thank the engineer-in-chief of the admiralty, Mr. Wright, for the information he has kindly supplied me with :

TABLE IX.

Comparative weights of cast steel and cast iron pistons.

Name of vessel.	Diameter of piston, in inches.	Description.	Material used.	Weight, in hundred weights.	Difference in favor of cast steel, in hundred weights.	Number of revolutions per minute.	Speed of pistons, in feet per minute.	Pressure on boilers, in pounds, per square inch.
Leander	78	Large piston	Cast steel.	32		90	720	90
					18			
Audacious, and others of the same class.	78	Both pistons of the same diameter.	Cast iron	50		70	420	31
Leander	42	Small piston	Cast steel	15		90	720	90
					5			
Assistance	42	Large piston	Cast iron.	20		80. 8	567	60
Espiègle	38	Small piston	Cast steel.	$9\frac{3}{4}$ }	mean $8\frac{5}{8}$	121	484	65
Miranda	38	....do....	....do....	$7\frac{1}{2}$ }		124	496	60
					$3\frac{1}{4}$			
Pegasus	38	....do....	Cast iron.	$12\frac{1}{2}$ }	$11\frac{7}{8}$	107	428	60
Dragon	38	....do....	....do....	$11\frac{1}{4}$ }		104	416	62

In the above table the weights of the *Leander's* pistons are *estimated.* The remainder are from *actual weights.*

The engines of the *Leander*, now being constructed by Messrs. Napier & Sons, are to indicate 5,000 horse power; somewhat in excess of those of the *Audacious* class, but the large piston of the former being of the same diameter, the comparison is interesting. Assuming the difference in weights to be correct, there is a saving in weight in favor of the *Leander* pistons of no less than 36 per cent., most valuable as applied to one of the principal moving parts traveling at a speed of 720 feet per minute, the engines working at 90 revolutions. Such a saving as 36 per cent. would amount to probably 130 tons in one of our large sets of commercial marine engines of 8,000 indicated horse power, provided the same percentage could be carried throughout, whilst a considerable saving by the substitution of this metal for wrought iron could be, in my opinion, beneficially effected.

With ship-builders straining every effort to reduce their weights in everything connected with the hull and its fittings, it clearly becomes a duty for marine engineers to do the same, and for the use of this metal there is, I feel confident, a great future; and it is to be hoped the committee of Lloyd's Register may see their way to have a series of experiments carried out on the relative strengths of this new metal and cast iron.

APPENDIX A.

Paddle-wheel sea-going vessels, built of steel, by Samuda Brothers.

Jason, built in 1859, for service in the Black Sea:

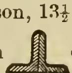
	Ft.	in.
Length between the perpendiculars	162	0
Breadth of beam, extreme	24	0
Extreme depth amidships	11	0
Burden in tons .... O. M. No. 452.		

Propelled by paddle-wheel oscillating engines of the collective nominal power of 100 horses, by John Penn & Son.

Cast steel made by Messrs. Marriott & Atkinson, Sheffield. Plates, £40 per ton angle bars, £40 per ton:

Tensile strain per square inch = 43 to 44 tons.
Flat keel, $\frac{5}{16}$ inch.
Garboard strake, $\frac{1}{4}$ inch.
Thence to upper part of bilge, $\frac{3}{16}$ inch.
Sheer strake, $\frac{1}{4}$ and $\frac{3}{16}$ inch.
Frames in engine-room, 18 inches apart, of 2 by 2 by $\frac{5}{16}$ inches.
Frames forward and after, 20 inches apart, of 2 by 2 by $\frac{1}{4}$ inches.
Floor angle bars, 2 by 2 by $\frac{1}{4}$ inches.
Gunwale stringer plate, 12 by $\frac{3}{16}$ inches.
Upper deck beam ties, 6 by $\frac{3}{16}$ inches.
Continuous angle bars of center, viz:
Two bars to keel, $2\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{3}{8}$ inches.
Two bars on tops of floors, 3 by 3 by $\frac{3}{8}$ inches.
Top angle bars of engine bearers, 2 by 2 by $\frac{1}{4}$ inches.

Puddled steel, made by the Mersey Steel and Iron Company. Plates, £25 to £27 per ton; angle bars, £17, £18, and £19 per ton:

Tensile strain per square inch = 44 tons lengthways, and 37 tons crossways of grain.
Bulkhead plates, $\frac{1}{8}$ inch thick.
Box-engine beams of $\frac{3}{16}$ inch plate, and 2 by 2 by $\frac{3}{16}$ inches angle bar.
Gunwale stringer angle bar, 2 by 2 by $\frac{5}{16}$ inches, best iron.
Floor plates, 11 by $\frac{5}{16}$ inches in engine-room, and $\frac{1}{4}$ inch forward and aft.
Intercostal plate of center kelson, $13\frac{1}{2}$ by $\frac{1}{4}$ inches.
Bilge kelson and sister kelson  of 2-inch angle irons, 3 by 2 by $\frac{5}{16}$ inches.
Upper deck beams, of angle irons, 6 by $2\frac{1}{2}$ by $\frac{5}{16}$, on alternate frames.
Cabin deck beams, of angle irons, 6 by $2\frac{1}{2}$ by $\frac{5}{16}$, on alternate frames.
Cabin deck stringer, 12 by $\frac{1}{4}$ inches, angle irons, $2\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{5}{16}$ inches.
Engine-bearers—side plates, $\frac{5}{16}$ inch; top plates, $\frac{7}{16}$ inch.

Maid of Kent, built for London, Chatham and Dover Railway Company, for Channel service, in the year 1861, entirely of puddled steel, supplied by Messrs. John Brown & Co., Sheffield, Thomas Firth & Sons, Sheffield, and the Mersey Steel and Iron Company:

Prices of plates varying from £20 to £27 per ton; prices of angles varying from £16 to £20 per ton. The tensile strain not under 35 tons per square inch.

Keel of bar, 6 by $2\frac{1}{4}$ inches, rabbeted to receive garboard strake.

Frames, 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches in engine-room, and 3 by $2\frac{1}{2}$ by $\frac{1}{4}$ inches, forward and aft, spaced 18 inches apart throughout.

Reverse frames, 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches in engine-room, extending to gunwale and 3 by $2\frac{1}{2}$ by $\frac{1}{4}$ inches, forward and aft, extending as high as bilge stringer. This vessel has very great rise of floor, and the reverse frames rivet to the main frames across middle line.

Middle line: Kelson formed of two thicknesses of plates, each 24 by $\frac{1}{4}$ inches, which plates shift butts with each other. This kelson rests on throats of main frames, and is attached to reverse frames, with two angle bars, 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches; also there are two angle bars on the top edge, 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches. The depths of this kelson and the strength generally is gradually reduced forward and aft.

NOTE.—The middle line and side kelsons and floors flush with top of same, formed seating for engine-bearers, and also formed boiler-room floor.

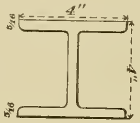
Side kelsons of plate $\frac{3}{8}$ inch thick, the top level with top of center kelson, and four angle bars 3 by $2\frac{1}{2}$ by $\frac{5}{16}$ inches.

Bilge stringers of 4 by 2 by $\frac{1}{4}$ inches bulb angle steel, and 3 by 2 by $\frac{1}{4}$ inches angle bar back to back.

Floor plates $\frac{1}{4}$ inch thick in engine-room, and No. 6 wire gauge (say 8.12 pounds per square foot) forward and aft. The tops of the floors are level with the tops of the middle line and side kelson. Short angle bars on tops of floor plates, 2 by 2 by $\frac{1}{4}$ inches.

Cabin-deck shelf or stringer of angle steel 5 by 4 by $\frac{5}{16}$ inches.

Shelf of 6 by 4 by $\frac{3}{8}$ inches angle steel riveted to reverse frames to receive the ends of the upper deck beams.

Upper deck beams 

spaced in each alternate frame.

Lower deck beams of 4 by 3 by $\frac{1}{4}$ inches angle bar, spaced on each alternate frame.

Poop beams of double angle bar, 3 by 2 by $\frac{3}{16}$ inches back to back. 

Poop cabin deck beams of 3 by 3 by $\frac{1}{4}$ inches.

Poop cabin shelf beams of 3 by 3 by $\frac{1}{4}$ inches.

	In engine-room.	Forward and aft.
Plating: Garboard strake	$\frac{3}{8}$ inch.	$\frac{5}{16}$ inch.
Bottom	$\frac{5}{16}$ inch.	$\frac{9}{32}$ & $\frac{1}{4}$ inch.
Sides	$\frac{5}{16}$ inch.	$\frac{9}{32}$ & $\frac{1}{4}$ inch.
Sheer strake	$\frac{5}{16}$ inch.	$\frac{5}{16}$ inch.

Poop plating = 4 pounds per square foot.

External gunwale angle bar 5 by 3 by $\frac{5}{16}$ inches broad flange, vertical } Gunwale stringer 12 by $\frac{1}{4}$ inches.

Bulkheads—plates $\frac{1}{8}$ inch, stiffeners 2 by 2 by $\frac{1}{4}$ inches.

Scud and *Foam*, built in 1862 for the London, Chatham, and Dover Railway Company, for channel service; and built entirely of puddled steel, supplied by Messrs. John Brown & Co., Sheffield, and by Messrs. Thomas Firth & Sons, Sheffield:

Prices of plates varying from £21 to £23; prices of angles varying from £18 to £21.

Tensile strain not under 35 tons per square inch.

Keel 6 by $2\frac{1}{4}$ inches, rabbeted to receive the garboard strake.

Frames for 40 feet amidships, 3 by 3 by $\frac{3}{8}$ inches.

Frames for 30 feet forward and 30 aft of this, 3 by 3 by $\frac{5}{16}$ inches.

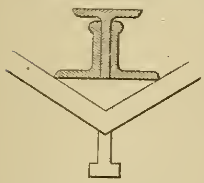
Frames remainder forward and aft, 3 by 3 by $\frac{1}{4}$ inches.

Frames spaced 18 inches apart throughout.

Reverse frames, of the same size as the frames they reverse, on each frame to gunwale for the extent of engine-room.

Forward and aft, on alternate frames, to extend to gunwale, and on intermediate frames, high enough to take bilge kelson.

These vessels have a great rise of floor; they have no floor-plates except a small bracket plate sufficiently wide (14 inches) to seal the middle line kelson.



Middle line kelson, of two bulb angle bars of 6 by 6 by $\frac{3}{8}$ inches, back to back, with a 6$\frac{3}{8}$ by 6$\frac{3}{8}$ inches tee bar riveted between them.

Side kelsons of two bulb angles, 6 by 6 by $\frac{3}{8}$ inches, back to back.

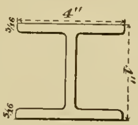
Bilge kelsons, each of a bulb angle, 6 by 6 by $\frac{3}{8}$ inch, and a 3 by 3 by $\frac{3}{8}$ inches angle bar, riveted back to back.

Cabin deck shelf of a bulb-angle sheet, 6 by 6 by $\frac{3}{8}$ inches.

Clamp plates, riveted to reverse frames about 2 feet below upper deck beams, made of two flat steel bars, each 4 by $\frac{3}{8}$ inches, worked all fore and aft.

Shelf of 6 by 4 by $\frac{3}{8}$ inches angle bar riveted to reverse frames to receive the ends of upper deck beams.

Main deck beams



spaced on each alternate frame.

Lower deck beams of 4 by 3 by $\frac{1}{4}$ inch angle bar, spaced on each alternate frame.

Poop deck beams of double angle bar, 3 by 2 by $\frac{3}{16}$ inch back to back

Poop cabin deck beams 3 by 3 by $\frac{1}{4}$ inches.

Poop cabin deck shelf 4 by 3 by $\frac{1}{4}$ inches.

Plating:

	In engine-room.	Fore and aft.
Garboard	$\frac{3}{8}$ inch.	$\frac{5}{16}$ inches.
Next strake..................................	$\frac{3}{8}$ inch.	$\frac{5}{16}$ & $\frac{9}{16}$ & $\frac{1}{4}$ inches.
Rest of plating to lower edge of sheer strake....	$\frac{5}{16}$ inch, diminished gradually to $\frac{1}{4}$ inch fore and aft.	

Sheer strake, $\frac{3}{8}$ inch for 40 feet amidships, diminished gradually to $\frac{1}{4}$ inch fore and aft.

Poop plating = 4 pounds per square foot.

External gunwale angle bar, 6 by 3 by $\frac{3}{8}$ and $\frac{5}{16}$ inches broad flange vertical.

Gunwale stringer plate, 18 by $\frac{3}{8}$ inches for about 70 feet amidships, reduced gradually to 12 by $\frac{5}{16}$ inches at ends.

Bulkheads of $\frac{1}{8}$ inch plate-stiffeners, 2 by 2 by $\frac{1}{4}$ inches.

APPENDIX B.

The following is a list of the various kinds of castings made, viz:

ENGINE CASTINGS.

Crank shafts.
Pistons—some very large for the Admiralty.
Eccentrics, rods and straps.
Crossheads.
Reversing quadrants and links.
Reversing levers.
Guide bars and slippers.
Hexagonal nuts (large).
Covers for bearings.
Toothed gearing, spur bevel and worm.

BOILER CASTINGS.

Manhole rings.
Manhole covers.
Safety valve chests.
Stop valve chests.
Seats for valve chests.
Branch pipes.
Necks for steam chests.

SHIP CASTINGS.

Propeller blades (single).
Propeller bosses.
Propellers (2, 3, and 4 bladed).
Deck sockets.
Combings.
Hawse pipes.
Anchors.
Patches for sternposts.
Thrust rings for screw shaft.

MISCELLANEOUS CASTINGS.

Mill gearing of all kinds from one pound up to 12 tons.
Brackets.
Rolls.
Locomotive, tram-car, and hutch wheels.
Wheels and tires for traveling cranes and bogies.
Faces and anvils for steam hammers.
Cress blocks for smiths' work of all kinds.
Railway and tramway switches, points, and crossings.
Shaft couplings, screw keys, spanners, clutches.
Riveting machine castings.
Locomotive bogie centres.
Cradles and rollers for carrying the ends of bridges.
Axle boxes and horn blocks for locomotives and railway carriages.
Shearing machine castings.

DISCUSSION.

Mr. DENNY. Last year I had the honor to bring before the notice of this Institution the case of a twin-screw steel steamer, built by my firm, which had been worked in the brackish waters of the Irrawaddy, and which showed marks of pitting along the water line. She was built of Siemens-Martin steel. Since then four paddle steamers have been put together, also of Siemens-Martin steel, and plying in exactly the same waters. I am happy to tell you that these vessels have been carefully inspected, and not a particle of corrosion found in any one of the four, after twelve months' service. I am also happy to inform you that in no case in any of the steamers built by us have we been able to trace corrosion, with one exception, and that instance is such an extraordinary one that I think it worthy of being brought before your notice. In the spring of last year we delivered to the Peninsular and Oriental Company a steel-screw steamer called the *Ravenna*, the first steel steamer ever built for that company. She was built entirely of steel and riveted with steel, but the stern frame and the rudder frame were made of forged scrap iron. The week before last I inspected this vessel in dock, along with Captain Angove, the superintending captain of the company, and Mr. Manuel, the superintending engineer. We found the skin of the vessel both above and below the water sound and free from corrosion, but we found on the stern frame under the first rudder band very serious pitting, extending in the space of twelve months to over three-sixteenths of an inch in depth. We also found in the forging of the rudder that there was a black corrosion or a black oxidization, and that in certain thin iron plates, used to cover in the open space between the sockets for the loose pintles of the rudder, that there had also been corrosion; but, extraordinary to say, on the large plates of steel which covered this rudder with exposed edges, both before and behind, there was not a single particle of corrosion. I think this is a very remarkable result, and well worthy of the attention of this Institution, because it seems to prove that it is rather a dangerous thing to mix up ordinary iron with steel. I believe Mr. Martell has had some experience on this subject before. I may mention at the same time that the propeller was a propeller with loose blades of cast iron, and these were pitted much beyond the common, so much so that the points of two of the blades were completely gone. I stated before you last year what evidence we had of corrosion, and I have stated this year the further evidence, and that further evidence has gone—with the exception of the one case of these iron forgings—to confirm our confidence in the reliability of steel. I think that the vessels to which Mr. Ravenhill has referred, in which the shell plating was very light, also go further to establish it; and that Mr. Ravenhill in bringing before us the exact scantlings of these vessels, and Mr. Samuda in permitting them to be brought before us, have done good service to the cause of steel, and have shown good reason for confidence in it.

Mr. Wright. The vast importance of mild steel for ship-building and boiler-making has absorbed so much attention that perhaps the use of mild steel for castings and forgings for machinery generally has not obtained so much attention as it deserves. I think that this Institution ought to be very much obliged to Mr. Ravenhill for bringing forward the subject as he has now. At this late hour I would only mention just one or two points, and one is the great value of steel for engines in the navy. In many cases you are aware that these engines have to be made on the horizontal plan, and with cast-iron cylinders; a great deal of trouble has been caused by the cylinder liners cracking. Since we have adopted cast-steel cylinder liners there has not been such a thing as cracked cylinder liners to give us trouble, and there is very little wear on the liners. There is great wear on the piston packing rings, but as they are simple and cheap and can easily be renewed, I take it that that is a matter of very little importance. The other point is the use of cast-steel for pistons, which Mr. Kirk is now introducing to a large extent. With modern engines the speed at which they run is increasing very much, and it is a matter of importance that all the moving parts should be made as light as possible, and the way to do this is to obtain the strongest and best material that can be used for the purpose.

Mr. Samuda. My lord, before we conclude may I be allowed, in confirmation of what has fallen from Mr. Wright, to say that I believe no greater assistance could be rendered to marine engineering and ship-building than this paper of Mr. Ravenhill's, calling our attention prominently, as it does, to the introduction of cast-steel. Cast-steel is getting itself introduced in many useful parts of the engine, and we also know that in riveting machines they are using cast-steel for the frames, but that the only material which has been unreliable in marine engines of late has been those parts which we have been obliged to keep of cast-iron. We have gradually gone on expelling cast-iron and substituting wrought, and now, if we can, as I hope and believe we can, we shall shortly almost remove the whole of the cast-iron and substitute steel, and then we shall have effected a very considerable improvement in the weight as well as in the strength of the material that we are using. With reference to the observations which Mr. Denny so ably brought before us just now, I have passing in my mind, at this moment, a most interesting paper which was read only just a week or two ago, at the Institution of Civil Engineers, in Great George street, which in passing I should like to refer to as being particularly applicable as regards ship-building. I do not think we ought to run away altogether from one particular position, which we must rely upon, and ought to rely upon, to prevent corrosion, and that is, that we do not expose steel at all to corrosion in the hull of our ships, because if we do we subject ourselves to a great deal of unnecessary destruction of material. If the material is properly prepared, and properly coated and painted, it is in that preparation and in that coating you have your security against corrosion. Now, the pitting which has taken place so extensively may be noticed and is noticed to be almost entirely remedied by proper preparations and coating. I recollect perfectly in the early stages of steel ship-building that two ships were sent out on the same service. One pitted so violently that it was incapable of being used within three or four months, and the other worked very successfully for years; and I believe the whole difference to have been this: that in the case of the successful vessel the steel at first had been allowed to rust, so as to separate the hard scale which is always produced in the rolling of the steel, and which if painted on tends more than anything else to produce the pitting process by allowing the water to get between the paint and the real skin of the steel. If that, after having been allowed to corrode, is struck off carefully and the paint is put on the solid steel, you have then the surface of the steel to depend upon.

Mr. Martell. My lord, I would just say one word with reference to Mr. Ravenhill's remarks—that he trusted Lloyd's Register would take this into consideration, and not stop the introduction of this material of cast-steel. We have admitted cast-steel for caps for masts, and for anchors, where it has been properly tested, for some time, and when so tested we have no objection to it whatever for certain purposes.

Mr. Ravenhill. I did not quite intend to convey what Mr. Martell appears to suppose; but I think Lloyd's Register would be doing good service to the country, such service as they have been doing here in connection with the *Livadia's* boilers, if they had some comparative experiments made that could be relied on between cast-iron and this new material—I call it that—which is now making under the Terre-Noire system.

Mr. Martell. One word with regard to corrosion that Mr. Denny and Mr. Samuda alluded to. That is a matter which requires very careful consideration before we draw any general inference. I may say that some twelve months ago a steel vessel was built which was riveted with iron rivets. I saw her after she had been running some time. She was placed on the slipway for the purpose of examination, and the result in that instance was contrary to Mr. Denny's experience, the steel around the rivet points being deteriorated to a considerable extent, whilst the iron rivets were perfectly sound. This was in the vicinity of the water-line, somewhat bearing out the experiments made by Mr. Phillips in his paper read before the Institution of Civil Engineers. This vessel was examined a month or two ago, and this part had not experienced any further deterioration than it had a year previously, and no doubt if she had been properly protected with paint or otherwise there would not have been the deterioration then found.

Mr. Kirk. I should be sorry that what Mr. Samuda has said should go abroad—namely, that cast-iron in engines was unreliable. Our engines are made two-thirds of cast-iron, and they are thoroughly reliable. In some recent engines we have used a good many steel castings, and in the engines we have now in hand for the fast cruisers of the *Iris* type we are using it more extensively. A great part of them were made by the Steel Company of Scotland, and they were found to be perfectly solid and good. As to the corrosion which Mr. Denny spoke of, it is just possible it may have been due to the air evolved from the water, because the corrosion of the stern-post went hand in hand with the corrosion of the back of the plate, which I think everybody must admit is due to the air.

The President. I think that our thanks are due to Mr. Ravenhill for his interesting paper. I am glad to say that practical testimony has been given to that paper, and therefore I thank him on your behalf.

ON THE USE OF MILD STEEL FOR SHIP-BUILDING IN THE DOCK-YARDS OF THE FRENCH NAVY.

By M. Marc Berrier-Fontaine, *Member.*

[Read at the twenty-second session of the Institution of Naval Architects, April 7, 1881; the Right Hon. the Earl of Ravensworth, president, in the chair.]

The council of the society having thought that its members might take some interest in being acquainted with the conditions under which mild steel is actually in use in the dock-yards of the French Navy for the construction of the hulls of ships of all classes, I am pleased to be able to satisfy the wish which has been expressed to me on this matter, after having obtained from the ministry of marine the necessary authorization.

I doubt, however, whether the information which it will be possible for me to give in the following note will add any very important matters of experience to those which have already been set forth by Messrs. Barnaby, Riley, Denny, Martell, and West, in the remarkable communications which have been read by them at former meetings of the Institution.

If in fact the French navy can justly claim the merit of having been the first to undertake boldly the substitution of mild steel for iron in the construction of the hulls of its largest fighting ships, it is necessary to admit that the British admiralty very quickly followed in this line.

If the French builders on their side can pride themselves on having been the first in a position to produce plates, angles, beams and bars, of all sections, presenting all the qualities of ductility, malleability, and homogeneity necessary to permit of their being used safely in the construction of war-ships, without its being necessary to have recourse to too delicate methods of work, it is also just to do credit to the wonderful rapidity with which the iron works of Great Britain have succeeded in obtaining steel plates and steel angle-bars fulfilling in the most satisfactory manner all the difficult conditions which had been clearly pointed out to them by the admiralty.

We may now, therefore, I think, admit that in a general way the experience and skill of the mild-steel makers are about equal on the two shores of the channel, and that a corresponding equality presents itself in the experience and skill of the builders who have to work this steel in the naval yards, both public and private, of the two countries.

It was on the 10th March, 1873, that the contracts were entered into at Lorient for furnishing the plates, angles, and rolled bars of steel necessary for the construction of the first-class armor-plated ship the *Redoutable*, which is entirely built of steel, with the single exception of the external plating of the wetted hull up to the lower armor shelf. The provision of this material it was possible to divide even at this time between two different works, that of Creusot and that of Terre-Noire. The keel of the *Redoutable* was laid on the 10th July, in the same year. About the same time, in August, 1873, the keels were laid of two other large vessels, also built throughout of steel, with the exception of the external plating of the wetted hull—the *Tonnerre*, a coast-guard ship of the first class, at Lorient, and the *Tempête*, a coast-guard ship of the second class, at Brest. I may here mention that the idea of the almost exclusive employment of steel in the construction of these first three ships belongs exclusively to their designer, Mr. L. de Bussy, then naval engineer at Lorient, and now director of naval construction at Paris. The quality of the steel employed in these constructions and the processes of working it have been completely described by M. J. Barba, then naval engineer at Lorient and now chief engineer of the works of Creusot, in his "Account of the Use of Steel in Naval Construction."*

In the month of October, 1874, Admiral Sir W. Houston Stewart, controller of the British navy, and Mr. N. Barnaby, director of naval construction, took the opportunity of seeing for themselves, and of studying on the spot, the use of steel in the dock-yards of Lorient and Brest. In the excellent communication "On iron and steel for ship-building," read on the 19th of the following March before this Institution,† Mr. Barnaby gave an account of his observations during this visit, and pointed out in the clearest and most precise manner to the steel-makers of Great Britain all the indispensable conditions which must be satisfied by the steel plates and rolled bars, so that they may be used with full confidence in the construction of the largest ships.

The conditions to be fulfilled having thus been clearly stated, it was not long before the steel-makers of Great Britain were in a position to satisfy them. The Landore-Siemens Company was the first to be able to fulfill them, and before the end of 1875 that company was in a position to contract with the admiralty for the steel plates and angle bars necessary for the construction of two high-speed cruisers, the *Iris* and the *Mercury*. These plates and angle bars were made from steel obtained by the Siemens-Martin process. Shortly afterwards the Bolton Steel Company was in its turn able to produce, by the Bessemer process, plates and angles satisfying all the requisite conditions. The Steel Company of Scotland, the Star Company, the Butterley Company, and other important works have also entered into the same business, and we are at last able to put full trust in the quality of steel furnished by these different works, as is now fully admitted by the constructors of the navy, the officers of the Board of Trade, of Lloyd's Register, the Liverpool Registry, and all the most competent authorities. Nothing could

* One vol. 8vo., 1st edition, 1874; 2d edition, 1875; published by J. Baudry, Paris and Liége.

† Transactions I. N. A., vol. xvi, 1875, p. 131.

well be more instructive than a comparison of the doubts and hesitation expressed by Mr. Barnaby in 1875, and the unlimited confidence expressed by Messrs. W. Denny and West in 1880. This is perhaps the best proof that could be given of the marked progress made in England in this matter in the short space of five years.

But while the steel-makers of Great Britain were thus progressing so rapidly and remarkably in the quality of their output, their competitors on the continent were far from remaining inactive. On our side of the channel, too, the manufacture of steel continued to make important progress, especially in respect of the homogeneity and perfect uniformity of the material turned out.

Such a steady and progressive improvement in the qualities of steel which are delivered to the French navy cannot be doubted. It is established by the result of all the trials to which the material has been submitted under the eyes and under the direction of the naval overseers before leaving the works. The proportion rejected by these has been steadily diminishing, and is now very small indeed. The ironmasters, moreover, have so completely mastered the quality of their steel that they can obtain with certainty qualities satisfying all the conditions for acceptance imposed upon them by the navy,* although not giving results markedly superior to those required by the said conditions. For instance, for plates from 6 to 20 millimetres thick, for passing which the breaking weight must reach at least 45 kilograms per square millimetre, and the extension at the moment of breaking must be at least 20 per cent., the ironmaster will naturally endeavor to obtain plates which give under test results slightly in advance of those which have been pointed out, so as to make sure that the plates will not be thrown upon his hands; but he is now able to settle beforehand his process of manufacture so as to obtain products of uniform quality with such precision that he can cut down almost to nothing the margin of safety that he needs to reserve. He will thus make his arrangements to produce plates which, upon testing, will seldom give more than 48 or 49 kilograms of breaking strain per square millimetre, or more than 22 or 23 per cent. of corresponding extension.

This certainty in the process of manufacture, moreover, is not the peculiar property of any one manufacturer. All the works, without exception, which furnish the navy with plates and rolled bars, are at the present moment in a condition to produce with certainty material whose tests will lie between limits equally close. This has been proved in the clearest manner by the results of the tests constantly made in the different works.† Thus not only do the products of any definite works present a perfect constancy of quality and a remarkable homogeneity, but this constancy of quality and this homogeneity may also

* See the Conditions of Acceptance, Appendix A.

† See Appendix B for an analysis of a great number of these tests applied to steel plates and bars delivered at the Toulon yard.

be found in the produce of all the different works to such an extent that it would not be possible to distinguish, one from other, the produce of different works, were it not for the manufacturers' mark stamped on each plate or each bar.

It must be added that this valuable quality of almost perfect homogeneity is not a consequence of the exclusive use of any particular process of manufacture. Steels made by the Siemens-Martin process and those turned out by the Bessemer process may now be regarded as absolutely equal in this respect, and the navy has been able now for several years past to admit with complete indifference the material turned out by both these processes, the names of which are not even mentioned in the terms of contract. Several manufacturers employ both processes simultaneously. If some of them reserve the Bessemer converters for the production of steels relatively of inferior quality, such as those for rails, and keep their Siemens furnaces for the production of superior qualities which have afterwards to be rolled into plates or bars for ships, other works, exactly reversing this plan, make rails from their Siemens-Martin steel, and reserve the produce of their Bessemer converters for plates and bars for the navy.

Such a divergence of opinion, which moreover, I am assured, is to be found also on the other side of the channel, appears to me to be one of the best proofs possible of the almost perfect equality of the two rival processes. For, if the superiority of produce obtained by either of them were undoubted and constant, it could hardly fail to have been long ago recognized by the constructors, who have to work up the steel obtained, and by the manufacturers themselves, who have not, as a general rule, any particular interest in either of the two processes mentioned, seeing that they habitually use them side by side.

The daily increasing homogeneity of the plates and molded bars which are used in our dock-yards does not seem to me, nevertheless, the only cause of the increasingly satisfactory results obtained in the various processes to which these materials are submitted in the yards. Our experience tends to prove, in fact, that the increasing familiarity of the workmen employed in these processes, particularly upon those plates and bars which are worked hot, has had at least an equal share in bringing about this fortunate result. Greater practice in using the new material, and increasing familiarity with it, if I may use such an expression, a more thorough knowledge of its qualities and of its defects—of its strong and of its weak points—in a word, of its behavior and of the special management which it requires so as not to produce failures, and even the confidence which is gradually showing itself in their treatment of it, are all causes tending strongly to the same end.

I have several times, for example, had to remark that it is not generally the workmen having most experience and skill in working iron who manage most quickly to understand the working of steel in the most satisfactory manner. Although this fact may seem paradoxical at first sight, there is nothing in it which ought really to surprise us; for skillful workmen, accustomed for many years to certain processes of work, and to certain sleights of hand which they have always found succeed, and and having, moreover, complete confidence in themselves, without reflecting that a metal which does not differ from iron in external appearance may yet possibly have different properties, will naturally treat it in the same manner. It is thus only after repeated failures that they become convinced that the new metal has a different behavior from that of iron. It is still later that they come to admit that this new metal, provided it is treated by them with a certain special care, is, taking it all in all, more manageable than iron, and able to bear, without danger, abrupt shaping which iron will not bear even when of exceptionally good quality. The younger workmen, on the contrary, have less settled habits, and at the same time they have less confidence in their own skill, and thus are more ready to conform with docility to the advice given them and the instructions which they receive; in a word, they have not got to unlearn anything, as is the case with their older and more skillful fellow-workmen. Consequently, when they are clever and intelligent, they are the first to understand how to work steel as it ought to be worked.

If, for instance, they have to submit to some rather trying treatment a piece of steel which cannot be completely finished before its temperature falls below a dull red, workmen skilled in handling iron will be disposed, even, according to their notion, in their employer's interest, to continue their work at a black heat, because they know that a similar piece of iron would not suffer from this, and before having gone through a fresh apprenticeship, they cannot realize, however often they may be told of it, that a similar piece of steel will not behave in exactly the same manner. The younger workmen, especially those who have not learned to work in iron before working in steel, are naturally free from these prejudices, and from this instinctive resistance to the advice given them. They will not hesitate to stop their work at once, as soon as it cools to a dull red, and to return the work to the furnace or the forge to give it the fresh heat that is sufficient in many cases to avoid the defects and injuries which their older and more experienced companions consequently find they have to pay for more often than their younger fellow-workmen.

It is hardly necessary to add that the more skillful of the iron workmen, as a rule, very quickly pick up the distance which their younger fellow-workmen, who had fewer traditions to unlearn, were able to gain over them in working the new metal. After some months, it is found that the balance is restored, and that the old skilled workmen have again taken the first place, which they had only momentarily lost. The best workmen for iron are then found to be also the best for steel, and in fact they soon take so kindly to the new metal that they would look only with contempt upon proposals to return to working in iron, a remark which has been very properly made by Mr. W. Denny in his very interesting communication "On steel in the ship-building yard," read by him last year before this Institution.*

It seemed to me that it might be interesting to go into some detail respecting this cause of the steady and progressive improvement of the results obtained in working steel, because it has not until now, so far as I am aware, been pointed out by anybody, although it has several times been brought under our notice in the most striking manner, especially during the first months in which the use of steel was largely developed in our dock-yards. I will quote what I consider a very conclusive example of the influence of this cause. The frame of the *Foudroyant* behind the armor-plating is formed of H or double tee-bars of 300 by 148 by 14 millimetres (Fig. 1, Plate IV), which being cleft at their two ends had to be bent into the shape represented on Plate IV, Figs. 1, 2, 3, the curve of the upper half having to be joined by a gusset piece to a similar curve in the corresponding deck-beam formed by a double tee-bar of the same scantling. This has always been attained without any difficulty, as might very well be, seeing that by the continuous character of the curvature in question, the strain to which this end of the piece of work was exposed, was evidently less severe than the forge test required before the same bars could be received, a test in which half of the bar has to be, not bent out upon a continuous curvature, but sharply bent, and almost folded at the joint, being kept straight for the rest of its length. The lower half of the bar was in quite a different case, having to bear a much severer trial than that of the receiving test,† one-half of the bar having to be bent at a right angle with a joining curve of very small radius. Again, among the first bars which had to be submitted to this trial there was a considerable proportion which could not bear it, the extension of the curved part taking place all at once on a very short length on one side or the other of the point of greatest curvature, marked A upon the figures, the thickness of the web being thus suddenly reduced at this point A so much that it frequently cracked. A considerable number of bars had to be thrown aside for this cause. When, however, we heard that the frames of the *Devastation*, a sister ship built from the same drawings at Lorient, had perfectly well borne this same work, we were naturally induced to suppose that our failure at Toulon was due to an inferior quality in the double tee-bars which had been delivered to us. Further experience, however, very soon convinced us that it was not so. The proportion of damaged pieces began steadily to diminish, and we soon came to have to reject none. It was not possible to attribute this improvement in the results to any corresponding improvement in the quality or homogeneity of the metal, since the whole of the bars necessary for the frames of the *Foudroyant* had been turned out from the same works

---

* Transactions I. N. A., vol. xxi, 1880, p. 188.

† See the conditions of this test, Appendix A.

and delivered together. It could have in reality no other cause than the improvement in the processes of work necessary to mold the different pieces mentioned; an improvement entirely due to the greater practice the workmen had obtained in getting them into shape.

It seemed to me all the more necessary to insist on the extent of the influence which increasing practice and skill on the part of the workmen could have upon the results obtained, inasmuch as the ship-constructors, who have only recently begun to make use of steel, and who have not yet got out of the period of failure due to the fact that the apprenticeship of their workmen is not yet finished, will find in this a reason for not being discouraged; when they know that their predecessors have had to go through the same trials and pass through the same ordeal of mistakes, but nevertheless succeeded pretty quickly in shaking off these small troubles as soon as their workmen had obtained sufficient experience of them, they will be more disposed to persevere. I think, therefore, that I am rendering a real service in persuading them to continue the use of a metal the superiority of which they will not fail soon to appreciate, although at first they may still entertain some doubts about its qualities.

There is a third cause whose influence in the improvement of the results obtained in working steel acts favorably for us. I mean the successive improvements which have been already introduced, and are being daily introduced, in the stock of tools in our shops. The new metal requires to be treated with much more care and precaution than iron. It will not bear, without suffering from it more or less, violent blows from iron hammers, or the irregular tears produced by using hand chisels. All the improvements in tools which can save us from having recourse to such blows and tears, and all those whose effect is to hurry the work on the plate while hot and to secure its being finished before the temperature of the stuff has fallen below the dangerous limit of dark-red heat—all these improvements in our tools, I say, cannot fail to contribute most effectively to the perfection of the results attained. As examples of the most important improvements in the tools that I mean, I may point out the following:

For the hot working of plates and angle bars, the replacing of common furnaces, which were used formerly, by gas-heated furnaces, in which the plates and molded bars can be raised to higher and more uniform temperature, has had for one of its results great economy of time and money, since the use of these new furnaces has enabled us to reduce in many cases the number of heats, and has given us much greater facility in carrying through the work itself, because the metal, being thus more strongly and uniformly heated, becomes much more malleable and ductile, and yields much more easily to all the changes of form to which it is subjected.

The already long experience of the works at Lorient, where furnaces on the Siemens system were in use from the beginning, has been fully confirmed on this point by the experience of the works at Toulon, where furnaces on the Gorman system have been preferred on account of their greater simplicity of construction and management. These last furnaces have been already at work for five years very satisfactorily, this result having been secured in great part by certain important changes in the arrangement of their gas-producers which experience has forced upon us.

The use of methods of mechanical traction, securing a high and steady speed without any sudden variations, has been developed as much as possible both for drawing the hot metal from the furnaces and taking it without loss of time to the points at which it is to be worked, and also for getting it into shape in a progressive manner without jar or shock. At Toulon we use for all work of this description two capstans driven by small hydraulic engines on Brotherhood's system, which, with the aid of return pulleys, suitably arranged, are employed also to control all the movements of the wagons running upon trams inside the workshop. As soon as a piece of metal is brought to a fitting temperature, it is seized in the furnace by pincers, to which a rope is made fast, which, passing over other return pulleys, goes to one of the two capstans. A workman starts it by pressing his foot on a lever close to the ground; a few turns, occupying only a few seconds of time, are enough to get the piece thus drawn on the bending floors alongside of the guides upon which it is to be molded; one of its ends being quickly fitted against these guides, the other end is clutched by a claw that is hauled upon by a cord seized upon one of the capstans; with a few turns of this capstan, which again only takes up a few seconds of time, the piece of work is brought to the required curvature steadily, without any sudden shock or jar, consequently without injury, and at a heat at which it still retains all its malleability. While the capstan thus does the chief part of the work, the hammer-men have only got to set right the parts which tend to start or buckle. Treated in this way it can be so rapidly brought into its final shape that it is still red when the work is finished, and the heat which it still retains is amply sufficient to anneal it without its being necessary to give it a fresh heat for the purpose.

The substitution of wooden beetles and mallets for iron sledge-hammers and mauls, which formerly were in almost exclusive use for working plates and molded bars, is a great improvement, although one which it has been most difficult to get the workmen to adopt. They assert, not without some reason, that even with equal weights they cannot obtain with wooden mallets, which are not so hard and which suffer compression, such strong and effective blows as those with iron hammers, which act upon a smaller extent of surface; but it is exactly these very strong pressures brought by iron hammers upon a limited portion of surface which tend to produce permanent local injury, these injuries being perfectly visible and due to the metal being crushed and tempered (so to speak) in a little ring, corresponding to each blow of the hammer, which is not possible without its having as a consequence lost some appreciable part of its homogeneity. We therefore insist in our workshops on the use of wooden beetles and mallets for working steel in all cases in which the shapes to be obtained are not too abrupt in form to render their use impossible. Experience has, moreover, shown us that good workmen quickly get to bend all plates of ordinary curvature, using exclusively wooden beetles and mallets, and that they are only obliged to use iron mauls or hammers for plates of exceptionally sharp curvature. In these exceptional cases it is necessary to be very careful to see that the work which has been subjected to such violence is carefully annealed afterwards.

The iron pins and rings which are ordinarily used for molding on the bending floors the curves to which the bars have to be wrought have, when steel bars are concerned, the great inconvenience of presenting but a very small bearing surface, on account of their small diameters, the result of which is that these pins often give a local nip to the flange pressed against them, which produces a more or less deep impression on that flange, or at any rate a bend, in consequence of which its curvature ceases to be regular. To avoid these inconveniences it became a practice to trace the mould, not directly by the help of pins and rings, but by a strip of plate previously bent to the proper mold and resting against the pins.* The exchange of pins and rings of small diameter for cast-iron discs of much larger diameter has allowed us to abandon the use of such aligning strips. The very useful introduction of these cast-iron discs, bored to receive the pin which fixes each of them to the bending floor, with a series of holes spirally arranged at progressively increasing distances from the outer circumference, was, I believe, introduced by Messrs. Denny. It was, at any rate, at their works, that I first noticed them. They have been introduced since into the tool supply of the Toulon works, where they have given perfect satisfaction.

We also regard as a marked improvement, the substitution of the progressive and steady pressure of hydraulic presses, for the sharp and violent jar of steam-hammers for all work involving strong curvatures or sharp changes of form. Thus the very extensive development of water-pressure machines allows us at the present day to obtain with great facility stamped pieces, quoted as examples by M. Barba,† as well as a great number of pieces of similar work, flanged, stamped, dished, or molded to sharp curvatures. Some examples of pieces of work thus obtained are represented on Plate IV, Figs. 4–8. So, again, water-pressure has been used with complete success in forming garboard plates and other bent plates. In all such cases the action of hydraulic presses, while quite sufficiently rapid, is so steady that it is seldom necessary to anneal the work subjected to it.

---

* Treatise on the Use of Steel in Ship-building, by Mr. J. Barba, second ed., p. 78.

† *Ibid.*, second ed., pp. 63 and 64.

The use of steady and progressive pressure is, moreover, at least as useful in the work done cold as in that which is done hot. Thus, also, the use of hydraulic presses gives the most satisfactory results when applied to the work of bevelling and molding angles or other work with sufficiently open curvature to admit of their being done cold. This is the case with all the deck beams, as well as for the greater part of the angles of the longitudinal stringers, and also for a very large proportion of the angles of the transverse frames. At Toulon this work is performed by presses of graduated power from 5 to 100 tons, some vertical, some horizontal, to suit all possible cases. One press of 100 tons is quite sufficient for the straightening and molding of double tee-bars of iron of 350 by 150 by 15 millimeters, and of steel bars of 300 by 148 by 14 millimeters, Fig. 1 (Plate V). The profiles of these are among the most rigid forms of all those with which we have yet had to deal. A press of 50 tons is sufficient for the straightening and molding of almost all the other forms that we use up to that of H or double tee-bars of steel of 250 by 130 by 10 millimeters, Fig. 2 (Plate V). Finally, the small 10-ton presses can easily mould steel angles of 150 by 150 by 15 millimeters, and 5-ton presses will mold steel angles of 120 by 120 by 12 millimeters.

I do not think it is necessary to-day to discuss at length the advantages to be found in the use of hydraulic machines of other types which we possess in the stock of tools at our plate-working shop, which is completely fitted with machines on this system, because the advantages in question are not special to working plates and rolled bars of steel, but are equally useful for the same work in iron. These advantages, moreover, have been fully explained and discussed by me in a separate paper read three years ago at a meeting of the Institution of Mechanical Engineers in Paris.* I cannot, however, pass over without remark the smoothness of work of the hydraulic machines for punching and shearing, the complete absence of jar or jerk in the speed of the tool at the moment that its edge comes into contact with the work to be punched or sheared. These are very advantageous conditions for working on steel which has to be treated with all possible care. Although I have not yet been in a position to undertake precise comparative trials on his subject, it seems to me to be very nearly certain that the action of punches or shears worked by hydraulic pressure must injure very much less the edges of the holes or cuts made in the steel plates, with consequently less damage to their uniformity than would arise from the use of a punch or shears driven by mechanical gearing, in which the tool always reaches the work with a considerable speed, the work being consequently exposed to more or less jar or jerk.

If, as seems to have been established by the comparative trials of

* "On the Hydraulic Machinery in the Iron Ship-building Department of the Naval Dockyard at Toulon:" Proceedings of the Institution of Mechanical Engineers, June, 1878. No. 3, Paris Meeting, p. 346.

which the results were communicated in 1878 to this Institution,* and to the Iron and Steel Institute,† the mere substitution of a punch with a helix for its cutting edge, which is thus brought to bear progressively on the consecutive portions of the circumference of the hole to be made (Kennedy's patent spiral punch) for the ordinary punch of which the cutting edge is in a horizontal plane, and is brought to bear all at once on the whole of the circumference; if, I say, this simple change is sufficient to insure that the metal shall be less upset on the edge of the hole we must also admit without hesitation that the greater smoothness of action of hydraulic punches and shears must have just as favorable an effect, and that the introduction of these machines must consequently tend to render less necessary the annealing process to which it is still considered desirable to subject steel plates and molded bars after they have been punched or sheared.

Again, with the object of avoiding for steel all useless "punishment," we take great care to rid ourselves of all processes which crack or upset more or less deeply the edges of the plates or the ends of molded bars, and which leave more or less irregular burrs. As Mr. Barnaby has very justly said, in a communication "On the use of steel in naval construction," read in 1879 before the Iron and Steel Institute, "When the end of a bar is cut off roughly, and is left ragged, the leaves break off suddenly if struck heavily, whereas the other end of the same bar trimmed off evenly will bear heavy sledging without rupture. The one end behaves far better than common iron would, the other far worse." These considerations have led us to forbid absolutely the use of the punch for making cuts in the plates, whether straight or curved, by a string of holes. In that respect again the exceptionally large gap of our hydraulic shears, which is uniformly of 1.50 metre or 5 feet, gives us a great advantage, for it allows us to shear the largest plates in any direction whatever, and to cut sheets of any length whatever up to 3 metres wide straight across.

As regards curved cuts, we obtain them at once by means of a series of blades having graduated curvatures, and brought sufficiently close to one another for them to cut out with sufficient exactness all shapes which can occur, whatever be their curvature. A collection of bent blades of this kind makes an outfit which is extremely valuable and I think quite new. I can give you no better idea of the shape of these blades than by saying that we can suppose them to be obtained by rolling the flat blades of a shearing machine around cylinders of selected radii, without altering the length of the blades or the inclination of their cutting edges; for curves of large radius, the blades thus molded can only give greater or less portions of the circumference of a circle, and several cuts are necessary to make a complete circle. If, on the other hand, the curvatures that one wishes to obtain are sufficiently sharp for

* "On Steel for Ship-building." By Mr. B. Martell. Transactions I. N. A., vol. xix, 1878, pp. 6 and 18.

† Journal of the Iron and Steel Institute, 1871, No. 1, p. 143.

the corresponding perimeters to be less than the length of the rectilinear blades, the bent blades really form large punches, which can cut holes of considerable diameter at one stroke.

I may mention, by way of example, that some of our shearing machines had been designed for cutting in a straight line, at each cut, a length of 65 centimetres. For circular curves of less than 10 centimetres radius, these blades become closed cylinders, which permit us to punch with one stroke circular openings up to 20 centimetres diameter. I would remark that if these closed blades had been actually obtained from rectilinear blades belonging to the same machines, by rolling the latter upon cylinders of suitable diameters, they would give, as in fact Kennedy's spiral punch does give, a sharp step with its riser following the generating line of the cylindrical surface upon which the two extremes of the rolled up blade would lie (Fig. 11, Plate IV). In order to avoid this inconvenience, which would weaken the blades and make it more difficult to whet them, while still retaining the screw shape for the cutting edge of all the open blades (Fig. 10, Plate IV), we give up this form for the closed cutters, and substitute for it in this case the elliptical form obtained by intersecting the cylindrical surface of the cutter by an inclined plane (Fig. 12, Plate IV).

I would finally point out, before leaving this subject, that the extension of the same principles has enabled us to adapt to our shearing and punching machines blades with two cutting edges (Fig. 13, Plate IV), used principally for splitting without distortion the ends of bars which have to be more or less open afterwards; the slope of these blades with two cutters is made equal to twice that of simple shears of the same machines. Or we may adapt to them a set of multiple punches, coming into play successively, which allow us to make both rapidly and economically the holes in deck plates (Fig. 14, Plate IV), as well as ventilating holes in bulk-heads (Fig. 15, Plate IV), &c.

The use of circular saws, and of endless saws which can cut steel cold, are equally useful to us for cutting off rolled steel bars, which, with the exception of angles, and, perhaps, of trough bars, cannot be cut with shears. In order to cut off or finish the ends of the greater part of these bars, it was formerly necessary to use either planing machines, the work of which was extremely slow and expensive, or to employ workmen with chisels and hand-hammers, of which the violent and repeated blows considerably upset the ends of the bars. By means of sawing cold we can, on the contrary, cut right across or in oblique directions bars of all sections perfectly clean and sharp without in any way injuring the ends of the bars, and without its being found necessary to anneal them after the work is finished.

I think we may say generally that the tools which carry out the most exactly the work which is to be done, whatever it may be, are at the same time those which least upset the neighboring portions of the pieces of work upon which they act. It is with a view of carrying this principle into practice that we do not hesitate, whenever it does not appear to us absolutely impossible to do so, to replace hand-tools, the work of which is always irregular and more or less coarse, by machine work, which, on the contrary, is always steady, regular, and uniform. We attach, moreover, particular importance in all our tools, of whatever nature they may be, to using nothing but steel of the best mark and of most carefully selected quality, however much higher the price may be. We, at the same time, take care that the working angles of these different tools shall be set as may be most suitable for each kind of work. Finally, we require that the most rigorous and the most unceasing attention should be given by the foremen and by the workmen themselves to seeing that the cutting edges of their tools are always kept in the most perfect condition. In order to secure as far as can be this last requirement, we have been induced to develop very largely the employment of grinding-machines, with artificial emery grindstones specially arranged for setting the tools of various forms, these machines allowing us to obtain a regularity and a precision of edge which it would be impossible to obtain by hand.

These artificial emery grindstones are also very useful for the work of taking off burrs, and finishing both plate work or rolled bars, as well as in finishing the small forge pieces, such as ring bolts, staples, hinges, and so forth, which enter so largely into modern construction. Formerly these things could only be executed with the file and chisel, which give much less satisfactory and more costly work.

It will be impossible for me, without exceeding the limits of time imposed upon me, to go into the complete detail of the saving which we have been able to obtain through the improvements in the tools, among which I thought it right to point out, as above, a certain number of the most important. I will therefore confine myself, in order to give an idea of the importance of the saving which we have thus been able to realize, to quoting a single example. The comparative trials, made with the greatest care, and prolonged though several months, have put us in a position to assure ourselves with perfect certainty that the simple replacement of the flat drills which, until then, had been exclusively used for our drilling work by twist drills of the best quality set with mathematical precision by the help of a small special machine with an emery wheel, has permitted us to effect in the execution of work of this nature a saving of very nearly one-quarter (exactly 22.2 per cent.).

I have endeavored to show in what goes before that three principal causes have mainly contributed, and still daily contribute, to the constant and progressive improvement of the results obtained in working steel plates and rolled bars, of which the framework of our ships now almost exclusively consists. This improvement has, moreover, led the constructors of the French navy to the same conclusion as their colleagues in the British admiralty: the possibility, and even the desisirability, of relaxing by slow degrees, but steadily, and continually more and more, the severe requirements which had at first been imposed by them for the execution of work of every description to which the plates and rolled bars of steel should be submitted in the dock-yards. We have already been able to introduce numerous and very important relaxations in the extremely rigorous and expensive precautions which had been recommended by the French constructors in 1874,* and specified as absolutely necessary by the English manufacturers up to as recent a date as the year 1879.†

It thus happens that the cases in which it is judged necessary to anneal steel plates and rolled bars are now incomparably less frequent than they used to be a few years ago, and the number is still undergoing daily reduction. Thus also it happens that we are returning by degrees to the use of the simple punch, without annealing and without reaming, for cutting holes in almost all the pieces of framework of the new constructions, reserving the use of the drill for those pieces only in which there is special reason for keeping up the greatest possible strength, having regard to the more important position that they have to take in the combination or the exceptional strains they may have to bear.

It is worth while, moreover, to remark that the very rigorous precautions to which the constructors were obliged to confine themselves as a matter of principle, when they began to make use of plates and rolled bars of steel, were principally—I might almost say wholly—intended to meet the local want of homogenity resulting from the strains, more or less violent, which the work had to undergo in the workshops, and that the precautions in question were directed beyond everything to prevent those singular breakages which then used to be common enough, and which gave all the more anxiety in that their true causes had not yet been completely ascertained.

If the constructors had not been influenced by the fear of seeing at every instant, and without apparent reason, such accidents produced, the exceptional precautions would have been set aside by them much sooner, and they would, consequently, long ago have submitted to the small loss of strength produced by the various manipulations through which these steel plates and molded bars have to pass; just as, for instance, they have always accepted, without any difficulty, the corresponding loss of strength which iron plates and rolled bars have to undergo. The most recent trials appear to prove that the loss of strength in question is not much greater in these cases for steel than for iron.

It seems to me, therefore, to be beyond doubt that at no distant period—that is to say, as soon as the breakage of steel work becomes sufficiently rare not to require greater precautions in working these pieces

* "Treatise on the Use of Steel in Ship-building," by Mr. J. Barba.

† "On the use of Steel in Naval Construction," by Mr. N. Barnaby: Journal of the Iron and Steel Institute, 1879, No. 1, pp. 47, 48.

than those which are applied to iron—we shall very soon get into the way of punching nearly all the steel plates and rolled bars, and of only annealing them in exceptional cases, when they may have been submitted to very violent and very trying deformations; a treatment, in fact, precisely similar to what we give to iron under the same circumstances.

Notwithstanding the very considerable relaxations which have been introduced into the precautions which had been thought necessary at first, the proportion of fractures which occur in working steel plates and bars (fractures of which a minutely exact account has been kept) has been steadily diminishing, and is now reduced to an extremely low proportion. In the table, page 144, I have collected, with a few unimportant omissions, the results obtained in this respect in the works of the five principal French dock-yards, and in those of the "Société des Forges et Chantiers de la Méditerranée," at La Seyne, near Toulon, from the time at which steel was first introduced on a large scale up to the end of last year. The figures of this table show that the proportion of fractures which occur in working steel has now become extremely small. As has been well remarked by Mr. W. Denny,* if we were to take as careful an account of the corresponding accidents which occur in working plates and bars of iron, we should probably be very much surprised to have to admit that the frequency of accidents of this nature is, in proportion to the total weight of the material used, at least as great, and perhaps even greater, for iron than for steel.

I will only mention briefly a fact which proves to what extent the results obtained in working steel are still capable of improvement accordingly as the quality of this metal becomes more and more satisfactory, and as the workmen who have to deal with it get accustomed to treat it by the processes which suit it best. It cannot be denied that only a few years ago the constructors considered weldings of steel plates and bars as difficult to execute in a thoroughly satisfactory manner. At Lorient it was the practice to effect these weldings by putting an iron liner† between the two surfaces of steel which were to be welded together. When it was necessary to use angle irons with sharp angles more or less departing from a right angle, the practice of the same workshop was, not to cut the portion which had to be kept flat, so as to avoid the necessity of having afterwards to weld it. They confined themselves, therefore, to hammering the work so as completely to flatten down this part. This was a very long and expensive process. In other workshops the foremen smiths, in order to effect the welding of steel, had recourse to the use of mixtures of very curious character and containing the most extraordinary materials.

Thanks to the more complete homogeneity and ductility of the steels

* "On Steel in the Ship-building Yard," Trans. I. N. A., vol. xxi, 1880, p. 187.

† "Treatise on the Use of Steel in Ship-building," by Mr. J. Barba, second edition, p. 88.

which are now delivered by the manufacturers, thanks also to the increased practice which our workmen have acquired in using the new metal, the welding of steel plates and bars can now be effected as easily, as simply, and as satisfactorily as that of similar work in iron, without its being necessary to have recourse to any special process or to the use of any particular flux. A great number of weldings of steel plates and angles have been broken as tests, and the results of these tests, in which the fracture often takes place outside the weld, have finally led us to consider the welding of thin plates of steel as being as certain and perfect as that of similar pieces of iron. Our experience, therefore, fully confirms that of the English and Scotch builders, whose results have been stated by Mr. Martell and Mr. Kirk, at one of the recent meetings of the Institution.*

The communication of Mr. H. H. West "On steel for ship-building,†" led last year to a very interesting discussion relating to the determinateness of the conditions of resistance and elongation which it would be best to require for the acceptance of steel plates and bars intended for use in the hulls of ships, with a view of deriving all possible advantage from the substitution of this new metal for iron, which had been previously almost exclusively used for work of this kind. Mr. West, and with him the greater part of those who took a share in the discussion, expressed the opinion that it would be necessary with this object to raise considerably the inferior limits required for tensile strain by the admiralty, by Lloyd's Register, and even by the Liverpool Underwriters' Registry. Mr. West's opinion is that we ought to fix at 30 tons to the square inch, or 47.25 kilograms per square millimetre, the inferior limit of tensile strain for accepting steel plates or bars intended for use in ship-building, and that we ought at the same time to abandon any superior limit for this tensile train. I have thought that it might be interesting to give a summary account, in a form admitting of comparison, and in fact in the very form used last year by Mr. West, of the conditions of acceptance in force, firstly, for the French Navy; secondly, for the English Admiralty; and, finally, for the two most important classification societies, with regard both to tensile strength and to final elongation at the moment of fracture. They will be found in the table page 146.

It is worth while to remark, in the first place, that the conditions of tensile strength and elongation which have been adopted in England apply alike to all steel to be used in ship building, whether in the form of rolled plates or bars of any thickness or profile whatever; while the French Navy has, on the contrary, fixed upon requirements of tensile strength and elongation which vary according to the thickness of the

* "On Steel for Ship-building," by Mr. B. Martell: Transactions I. N. A., vol. xix, 1878, p. 3. Also Discussion, Mr. A. C. Kirk, p. 26.

† Transactions I. N. A., vol. xxi, 1880, p. 208.

plates and bars, or the sectional profile of the bars. The different limits thus specified in the French Navy depend upon experimental results, and should not be regarded as absolutely unchangeable. Already, in fact, as is shown in Appendix B, some of these limits have been altered, and it is certain that others in their turn would be so if the necessity for it became evident. It must also be admitted that the limits of tensile strength now imposed, still present some singular anomalies, among which we may mention the very great relative difference of 4 kilograms per square millimetre which there is between the limits of tensile strength required for steel butt straps, according to whether these are tested along or across grain, and the reduction in tensile strength of 2 kilograms per square millimetre which is allowed between double tee-bars and simple tee-bars or bulb bars (Plate V. Figs. 1–4), as compared with the lower limit required for bars of all other descriptions. Without attempting to explain these few anomalies, which further experience in the use of steel will doubtless cause to disappear before long, I wish to point out that, excluding boiler steel, for which an exceptional amount of ductility is considered indispensable, the inferior limit of tensile strength required by the French Navy is, as a general rule, higher than that specified by the English Admiralty, by Lloyd's Register, and even by the Underwriters' Registry. It is only, in fact, for the thicker plates of from 20 to 30 millimetres, and for the bands and butt straps of all thicknesses, worked across grain, that the French Navy allows a lower limit of 44 kilograms per square millimetre, equal, very nearly, to that of 28 tons to the square inch, or 44.1 kilograms per square millimeter, which is specified for all through by the Underwriters' Registry for all steel used in the hull. As the thickness of the plates diminishes, the inferior limit required in the French Navy increases progressively, and for plates of from 6 to 20 millimetres in thickness, which includes nearly all those used in modern constructions, this limit exceeds by 1 kilogram per square millimetre that of the Liverpool Society. In order to be accepted for use in the French Navy, thin plates from 1 to 4 millimetres thick must be subjected to a minimum test of 47 kilograms per square millimetre, which is nearly equal to the inferior limit of 30 tons to the square inch, or 47.25 kilograms per square millimetre, which Mr. West would wish to see adopted; while the minimum tensile strength of the bands and butt straps tried along the grain, and that of bars of all sections with the exception of double tee-bars, tee-bars, and bulb-iron, should be of still higher tensile strength, namely, 48 kilograms in place of 47.25 kilograms per square millimetre.

If we remember, besides, that in the French Navy there is no superior limit to the tensile strength of steel presented for acceptance, it will be seen that the final result of the conditions required by it has been to furnish it with steel plates and bars having an actual tensile strength very considerably in excess of those of the similar pieces of steel which are used for the same work in the building yards of Great Britain. We must admit at the same time that this superior tensile strength is not in the French Navy purchased at the cost of a reduction of ductility in the steel there employed, since a minimum elongation of 20 per cent. at the moment of breaking—that is to say, an elongation equal to that required by the British Admiralty and by Lloyd's Register*—is specified for all plates of which the thickness exceeds 6 millimetres for tee bars of more than 4 millimetres, and for angle bars of from 4 to 6 millimeters thickness, while the elongation must exceed 22 per cent. for bands and butt straps tested along the grain, and for angles and bulb bars of more than 6 millimetres in thickness. It is only, in fact, for double-tee and bulb bars of all thicknesses, for bands and butt straps of all thicknesses tested across grain, and for plates, angles, tee-bars, bulb bars, and so forth, of less than 6 millimetres in thickness, that is to say, for descriptions of plates and bars in which ductility is evidently of less importance, that the French Navy allows of a final elongation at the moment of fracture less than the 20 per cent. which is required by the Admiralty and by Lloyd's Register.

In short, engineers who think with Mr. West, that the tests of tensile strength now required in England for the acceptance of steel intended for ship-building are not severe enough, and that the lower limit of these conditions should be considerably raised, may, as will be seen, find a very conclusive argument in favor of their opinion in the practice of the French Navy. It is for this reason that it appeared to me to be of interest to treat this subject in some detail.

The actual results of the tests for acceptance, of which a considerable number have been collected in a tabular form in Appendix B, show that the true mean resistance of steel plates from 6 to 20 millimetres thick, which are those in ordinary use, cannot be estimated at less than 48 kilograms per square millimetre, and that it therefore exceeds the minimum of 30 tons per square inch, or 47.25 kilograms per square millimetre, proposed by Mr. West; but it is necessary to consider that several tests have only shown a resistance equal to or even less than 46 kilograms per square millimetre without these plates having been rejected. It would therefore appear to us to be imprudent to adopt at once an inferior limit of from 47 to 48 kilograms per square millimetre for the acceptance of plates which are now admitted as low as 45 kilograms per square millimetre. In fact, notwithstanding that the navy assigns no superior limit to tensile strength, such a limit is implicitly involved, at least to a certain extent, in the condition of minimum elongation that is required, and the effect of adopting a higher figure for the lower limit of tensile strength would in reality have the effect of making the range

*The length of the test pieces is practically much the same on both sides of the channel, 200 millimetres in the tests for acceptance in the French Navy, 8 inches or 203.2 millimetres for the tests of the British Admiralty and Lloyd's Register. The tests for elongation are therefore perfectly comparable.

of tensile strength between maximum and minimum, within which steel would be accepted far too narrow. The result would unquestionably be that manufacturers, finding themselves thus exposed to the chance of more frequent refusals, would not fail to guard themselves against such an increase of the risk that they run by raising their prices accordingly.

Economical considerations of the same character, to which we must add others connected with the necessity for keeping down the delay involved in replacing material which has been rejected, and, consequently, with the rapidity of the execution of orders, decided the French Navy in the adoption, now some years old, of the system of acceptance or refusal at the place of manufacture, under the superintendence of engineers specially told off for this service, for all plates and rolled bars, and generally for all forms of steel and iron of any importance, for which requisitions are made on the private trade. This proceeding has not been lightly adopted, a long and minute inquiry having been begun in 1869, and carried on during several years, in the course of which all competent authorities have been called upon to express their opinion upon the advantages and inconveniences which they thought might arise from the application of the tests outside the ports of consignment. The advantages of effecting the tests in the manufactories, and settling the acceptance there, have been, moreover, thought so evident and so important, that everybody, almost without exception, thus consulted, has given an opinion favorable to the continuance of this policy. The inquiry, therefore, came to an end in 1873, and since that date absolutely nothing has occurred to throw a doubt on the wisdom of the decision thus taken. It is very certain, on the contrary, that the settlement of acceptance or rejection before the dispatch of the iron and steel saves the supply of the materials from a very important part of the accidental risks which manufacturers have some reason to dread, and that by facilitating the business between the manufacturers and the navy, its result is to lower the price considerably; at the same time—and this last advantage is still more important—the service of the dock-yards, of which the requirements are frequently urgent, is thus secured more quickly and more satisfactorily, since it is not exposed to suffer the long delay which rejections of material could not fail to involve if they were only settled after delivery of the material at the ship-building yard.

As regards the calculations of tensile strength, it appears from the results of the tests which have been already carried out in considerable number, that we may adopt the mean figure of 48 kilograms per square millimetre as representing the ordinary breaking strain of steel plates and rolled bars such as are actually used in the French Navy. The ordinary breaking strain of the iron plates and molded bars of ordinary and common qualities which are delivered to it cannot, on the other hand, be regarded as greater than 36 kilograms per square millimetre at the outside. For iron we generally use a factor of safety of 6, that is to say, that we look upon 6 kilograms per square millimetre as the limit of the load that we consider proper to put upon it in ship-building. Using the same factor for steel, we reckon that plates and molded bars of this metal may be safely loaded with 8 kilograms per square milimetre.

The limiting loads of 6 and 8 kilograms per square millimetre, which have just been mentioned, are to one another as 1 : 1.33, consequently the inverse ratio of 1 to 0.75 indicates the reduction of thickness, and, therefore, of weight which the substitution of steel for iron allows us to introduce into the plates and rolled bars which we use. This corresponds to an economy of 25 per cent. in the weight of a hull of given dimensions and form.

In order to take account of the loss of strength experienced during the work—a loss, which, as we know, may well be of greater relative importance in steel than in iron—in order to take account, besides, of the existence of an inferior limit below which we cannot reduce the thickness of steel plates without risking their buckling, and although there does not exist any general formal rule about this, the constructors of the French Navy, in agreement with the authorities of Lloyd's Register, think that it is not safe to reckon on a final saving of more than 20 per cent. in the replacing of iron by steel in the weight either of the whole hull or any part of it.

The total amount of this reduction being thus fixed, the French Navy has never experienced the slightest difficulty in procuring steel plates and rolled bars of suitable thicknesses or scantlings to secure this saving of weight. As several engineers have very justly remarked at the preceding meetings of the institution, if the reduction of 20 per cent. were to be uniformly and separately applied to the thickness of each of the pieces which are to enter into the construction, doubtless there might be some difficulty in getting at it; but it is easy in the practical application of this reduction to introduce numberless compensations, and consequently to reach the desired reduction on the whole of the construction. In accepting the tenders for the French Navy care is always taken to specify for the plates the weight per square metre of each millimetre of thickness, and for rolled bars the weight per metre run; these fundamental weights being always calculated on the assumption that the plates and rolled bars of steel have a mean specific gravity of 7.8. We specify, moreover, that the weights thus indicated are never to be exceeded. The only departures which are permitted are in defect, and of this the following are the limits generally adopted: For rolled bars of every section, 5 or 6 per cent., accordingly as their scantlings are greater or less; for plates of 1½ millimetres, 12 per cent., this margin of 12 per cent. diminishing by 1½ per cent. for every millimetre of extra thickness up to 5 per cent. for plates of 15 millimetres and all greater thicknesses. It is finally stipulated that these thicknesses are only pointed out as mere approximate guides. These arrangements practically come to ordering both plates and rolled bars by weight instead of by thickness. The French makers, whose interest it is to keep as nearly as possible to the higher limit pointed out to them in each case, seeing that the plates and rolled bars are paid for by their actual weights, have, like their colleagues in England, never found the slightest difficulty in executing orders given to them under these conditions.

A very important question, which has already been discussed during the preceding meetings of the Institution, especially in 1878, in the able communication of Mr. Martell "On steel for ship-builing,"* is one that concerns the interests that shippers may have, from a strictly commercial and economical point of view, in exchanging iron for steel in the construction of their ships. The examples quoted by Mr. West show clearly that the actual cost of a ship built in steel was still, three years ago, considerable greater, in the proportion of 9 to 8 nearly, than that of a ship of similar form, and of the same external dimensions, built in iron. The choice of steel for the construction of a ship could thus only bring about under these conditions as the practical result an economy, as Mr. Martell has endeavored to explain to us, from the greater profits which such a ship would bring if built in steel, thanks to a larger proportion of total weight remaining disposable for cargo. The discussion which took place brought out that, at any rate at the time we are speaking of, the practical advantage that could thus be realized by shippers was still far from being uncontested.

Without entering afresh into the discussion of the very different opinions which have been held on this point, I will content myself with bringing under notice how much this divergence of views loses of its importance if we look to the future, and that undoubtedly the immediate future. It is in fact permissible to predict, almost with certainty, that the price of plates and bars will continue to get lower and lower pretty rapidly, and that consequently the time will soon have come when the cost of a ship built in steel will not exceed that of a ship of similar form and of equal dimensions built in iron. We are even bound, having regard to the increasing experience, skill, and ability of workers in steel, to predict that in the not very distant future, plates and bars of steel (of which the manufacture requires even now, after all, neither more handiwork nor more fuel) will ultimately cost no more than similar plates and bars of iron. The advantages of the use of steel in the construction of merchant ships will not then fail to be completely appreciated by all charterers without exception, who will be in a condition to profit by it to secure ships presenting, in comparison with iron ships of similar form and equal external dimensions, the following various causes of superiority: A lower cost price, a much lower weight

*Transactions I. N. A., vol. xix., 1878, pp. 7 *et seq.* See also the discussion by Mr. C. H. Wigram, Mr. W. Denny, and others, pp. 24, 25, &c.

of hull, and consequently an effective paying tonnage increased in the same proportion, and finally a hull built of more ductile material, and therefore less liable to receive serious injury from grounding, from slight collisions, and so forth, from which no ship can be exempt.

For the French Navy, that uses exclusively iron of the best quality, of which the price is considerably greater than that of the iron employed in building merchant ships; the hull of a steel ship comes out already at a lower price than the hull of a ship of similar shape and equal dimensions built of iron. This result is due to the considerable reduction that the price of steel has undergone within eight years, and in consequence of which the prices of steel plates and angle bars are now sensibly equal to those of iron plates and angles. This does not quite hold, it is true, for molded bars other than angles. The price of these is still higher in the proportion of 1.85 to 1, or thereabouts, than that of similar bars of iron. That is an anomaly which I find some difficulty in explaining, but which time and the increased competition between the different works will doubtless not be long in causing to disappear. However this may be, the molded bars we are speaking of only enter to a small extent into the total weight of a ship, and their higher actual price is even now an insufficient set-off to the savings which result, on the whole of the construction, from the replacing of iron plates and angles by steel plates and angles, of which the price is not markedly superior, while their total weight moreover may be 20 per cent. less.

I have collected an account of the ordinary prices paid in the French Navy for the steel of different shapes used in it, these prices having been calculated from the different tenders accepted by it during two different biennial periods, the first comprising the years 1873 and 1874, during which the use of steel was largely developed for the construction of the ships of the fleet, the second period comprising the last two years, 1879 and 1880. A comparison of the mean prices thus brought together shows that in the interval of six years which separates the two periods named the mean price of steel plates has fallen 55 per cent. and that of steel angles 56.2 per cent., while the price of rolled steel bars, not being angles, has only diminished during the same interval of time by 20.6 per cent.

I have also ascertained, for the sake of comparison, the mean price of iron of different shapes which has been delivered to the navy in compliance with a certain number of contracts entered into on its behalf for some years. Finally, I have applied all these mean prices, obtained, as I have said, to the total quantities of plates and molded bars both in steel and iron which have been actually ordered for the construction of the hull of the first-class iron-clad the *Foudroyant*. and I have calculated within what comparative limits the total weight and the total cost of the material would be altered in each of the two hypotheses following: first, supposing this particular iron-clad to have been built entirely of steel, including even the exterior part of the hull; or, secondly, altogether of iron. It appears from this last comparison that if we took severally for unity the total weight and the total price of the iron which would have been required in a case corresponding to the last of the preceding suppositions, the substitution of steel for iron in all parts of the construction, with the exception of the external plating of the hull, would permit us at the present day to effect a saving in weight of 17.05 per cent., and a saving in cost of 7.95 per cent., while if, moreover, the external plating of the hull had been also made in steel the savings in question would have become as follows: In weight, 20 per cent., and in cost, 12.4 per cent.

I cannot drop this subject without pointing out that a fighting ship is not, like the merchant ship, designed to carry a cargo of which the weight may be left undetermined within certain limits, subject only to its being possible to retain the same displacement when fully loaded, with the same dimensions and the same external form when the weight of the hull is either increased or diminished, provided always that this increase or diminution of weight in the hull is compensated for by a corresponding diminution or increase in the weight of the cargo. A ship of war, on the contrary, is constructed to fulfill certain perfectly determinate conditions: to carry, for instance, an armament of which the total weight is exactly fixed beforehand, and which cannot be reduced without bringing about a corresponding reduction of one at least of the qualities which had been agreed to as being necessary. The weight of the hull of such a ship cannot therefore be increased without involving as its necessary consequence a corresponding increase of capacity, and a further increase in the weight of the driving machinery if we wish the enlarged ship to retain the same speed; and, again, an increase in the coal supply if we wish this new ship to be capable of steaming the same distance, and so forth; that is to say, we are involved in a whole series of increments which all tend towards the same result—a considerable increase in the dimensions and total weight of the ship when ready for sea. If, for example, the hull of the *Foudroyant* had been built of iron instead of steel it would have been necessary to increase its dimensions considerably, and we cannot estimate this increase at less than 1,600 tons for the load displacement. I do not think it is necessary to reason out any further these considerations in order to put in a clear light the importance of the marked saving which the substitution of steel for iron now permits us to secure for ships of war.

As I have said before, the constructors of the French Navy have thought it necessary, up to the present time, to adhere to the use of iron plates for the outer plating of the hulls of all vessels of any importance which form part of the fleet. The difficulties which we formerly had to encounter in fashioning steel plates into the abrupt and varying forms which had to be given to the garboards and to the plates at the two ends of ship, difficulties pointed out in 1875 by M. Barba,* must not

* *Op. cit.*, p. 4 of introduction.

be looked upon at this day as among the reasons which still actuate the directors of the navy in not carrying the use of steel into the parts in question, since it is now clearly shown that steel plates can practically be brought to such shapes, if they are suitably treated, even more readily, more satisfactorily, and with better chances of success than iron plates of the most reliable quality.

Among the reasons which were formerly stated for retaining the use of iron in the exterior plating of the hull there is only one which still exists, and that is the uncertainty which still remains as to the behavior of steel plates in sea-water. It must be admitted that the experience of the French Navy, although by no means very extensive on this point is not conducive to the abandonment of iron plates for the special purpose in question, for there is evidence that steel plates, when wetted with sea-water, rust much more quickly than iron plates do under similar circumstances. It also appears that the conditions on which the corrosion of steel plates depend are extremely complex, and that they are, for instance, much more active in the comparatively warm water of the Mediterranean than in the colder water of the ocean.

I will quote as examples two gunboats, the *Epée*, built at Lorient, and the *Tromblon*, built at Toulon, whose hulls, completely steel plated, have each of them given proof of rapid and deep corrosion. The *Epée*, however, could be kept afloat in the brackish and muddy water of the port of Lorient, formed by the Scorff River. The *Tromblon* was launched at Toulon on the 30th January, 1875, and remained afloat until the 27th October of the same year. During that period of nine months it has been necessary to dock her three times, that is to say about every two months, to paint the hull, the plates being so rapidly and deeply attacked, especially in the neighborhood of the water-line. Instead of spreading more or less uniformly over the whole surface of the plates, as usually happens with iron hulls, the oxidation seemed to spread by preference in the direction of the thickness of the plates from the points which were first attacked, by forming a series of pittings of great relative depth, and if there had been any considerable delay in repainting the hull in the neighborhood of the water-line, the plates, the thickness of which does not exceed 5 millimetres, would have been quickly perforated at a good many points. Finally, the progress of the corrosion of the this steel-pated hull went on with such unusual rapidity that when the time came to pass the *Tromblon* into the reserve, it was thought necessary, instead of keeping her afloat, to haul her onto a slip, where she will be kept dry until fresh requirements of service oblige her to take the sea again.

It is very likely that the true causes which govern this phenomenon of exceptionally quick oxidation in steel plates wetted with sea-water will one day or other be completely investigated. When the causes of the evil have thus been determined it may be easier to find a remedy for it, but it must be admitted that the experiments which have been made on the subject at various places have not yet given very conclusive results. It would not be safe to affirm very positively, for instance, that this extremely rapid corrosion of steel plates is solely due, as Mr. Barnaby* assumes, to intense galvanic action arising between the metal and the black oxide by which it is covered, and that consequently it will be sufficient to clear the plates of this black oxide by means of a weak acid bath in order to make their oxidation in sea-water slow and uniform, like that which usually takes place on the surface of iron plates. It could not be affirmed with any certainty either that the greater or less rapidity with which steel plates are attacked by rust depends solely on the greater or less proportion of manganese which they contain, as has been suggested by Dr. Siemens, in 1878, before this Institution, a suggestion, however, thrown out with some degree of doubt.† Finally, it cannot be affirmed, as has been recently stated before another society, that the corrosion of iron and steel plates is the more slow and regular in proportion as those plates contain a greater proportion of carbon or phosphorus, and that it is consequently not possible to find plates which possess the necessary ductility in combination with the valuable property of being attacked by rust only in a slow and regular manner when exposed to sea-water.

The very diversity of opinion which I have just mentioned proves clearly that these statements can only be received as suppositions agreeing more or less roughly with the observed facts. Whatever be their real value, the French Navy, paying attention principally to the positive lessons of experience, acts doubtless prudently in refusing to substitute steel for iron in the external plating of its ships while there remains any uncertainty as to the causes which bring about on the surface of steel plates in sea-water such abnormal oxidation as has been observed upon the hull of the *Tromblon*, and until we discover more effective methods of guarding against such deep and rapid corrosion.

Finally, I must point out, in a few words, what are the reasons which have until now decided the French Navy in retaining the exclusive use of iron rivets to fasten together the various parts of its new constructions in steel, although in reality these reasons do not differ materially from those which have been several times stated before this Institution, especially in 1878, by Mr. White, and by Mr. John, in the discussion which followed the very interesting communication of Mr. Martell "On Steel for Ship-building."‡ The French constructors are, like them, verrfy a from assuming that the use of steel rivets may not some day give satisfactory results; but the cases in which steel rivets have hitherto been used do not seem to them sufficiently numerous, nor does the experience which results from them appear to have been sufficiently ex-

* "On the Use of Steel in Naval Construction." Journal of the Iron and Steel Institute, 1879, No. I, p. 53.

† Dr. C. W. Siemens in the discussion on Mr. Martell's paper "On Steel for Ship-building." Trans. I. N. A., vol. xix, 1878, p. 30.

‡ Trans. I. N. A., vol. xix, 1878, pp. 25, 28, 29.

tended, nor sufficiently conclusive, to allow of their considering themselves in a position to dispense at once with the use of iron rivets.

As Mr. White appropriately pointed out in the discussion which I have mentioned, on the use of iron rivets to connect the different portions of a steel frame, if we wish to preserve, as is suitable, the homogeneity of resistance in the joints, that is to say, equality of resistance between the rivets and the plates, it is only necessary to increase, in a very small ratio, the diameter of the rivets, or (which is preferable) the number of the rivets with a slight diminution of pitch. This proportionate increase may evidently be the less, accordingly as the tensile strength of the iron of which the rivets are made, approaches that of steel. Now the French Navy only uses for its rivets—the whole of which are manufactured in its own works—fine-grained iron, charcoal made, and of quite exceptional testing. To be accepted, this iron must undergo with success severe forge tests, and riveting tests, as well as breaking tests, in which the tensile strength on fracture must not come out below 35 kilograms per square millimetre, the corresponding elongation never being allowed to fall below 12 per cent., while the results actually obtained in these last tests usually indicate a tensile strength at fracture of from 38 to 42 kilograms per square millimetre, with a mean elongation of from 12 to 17 per cent.; that is to say, co-efficients of tensile strength and elongation not much below those of the mild steels which could alone be substituted for the iron in question as a suitable material for the rivets. It will be easily understood that, this being the case, the French Navy would apparently gain no advantage, so far as at present appears, from substituting steel for iron as the material for rivets, and that it consequently prefers to go on making use of iron rivets of the best quality, which offer a better guarantee of security than could at this date be found in the use of steel rivets.

Statement of the waste occasioned in working plates and rolled bars in steel used in the construction of ships for the French Navy.

Localities.	Period prior to November 1, 1877.			From November 1, 1877, to May 1, 1878.		
	Total weight of plates and bars used.	Percentage of weight.		Total weight of plates and bars used.	Percentage of weight.	
		Of pieces spoilt.	Of pieces unused.		Of pieces spoilt.	Of pieces unused.
	K.	Per c't.	Per c't.	K.	Per c't.	Per c't.
La Seyne	....	....	....	799,000	2.50	0.00
Toulon	1,159,000	0.97	0.39	580,000	0.00	0.00
Rochefort	157,000	(*)	C.21	124,000	(*)	0.04
Lorient	570,000	1.91	0.55	392,000	2.55	0.61
Brest	291.000	0.52	0.00	361,000	1.44	0.04
Cherbourg.	....	....	....	269,000	0.00	0.00
Total	2,177,000	†1.09	0.37	2,521,000	†1.39	0.10

Localities.	From May 1, 1878, to November 1, 1878.			From November 1, 1878, to May 1, 1879.		
	Total weight of plates and bars used.	Percentage of weight.		Total weight of plates and bars used.	Percentage of weight.	
		Of pieces spoilt.	Of pieces unused.		Of pieces spoilt.	Of pieces unused.
	K.	*Per c't.*	*Per c't.*	*K.*	*Per c't.*	*Per c't.*
La Seyne	514, 500	0. 35	0. 22	276, 000	1. 24	0. 00
Toulon	393, 000	0. 00	0. 00	333, 482	0. 00	0. 00
Rochefort	35, 000	(*)	0. 43	36, 968	(*)	0. 49
Lorient	429, 500	0. 04	0. 04	1, 013, 974	0. 32	0. 14
Brest	416, 000	0. 32	0. 00	578, 556	0. 14	0. 00
Cherbourg	52, 000	0. 79	0. 46	119, 145	2. 20	0. 19
Total	1, 840, 000	†0. 20	0. 09	2, 358, 625	†0. 33	0. 08

Localities.	From May 1, 1879, to November 1, 1879.			From November 1, 1879, to May 1, 1880.		
	Total weight of plates and bars used.	Percentage of weight.		Total weight of plates and bars used.	Percentage of weight.	
		Of pieces spoilt.	Of pieces unused.		Of pieces spoilt.	Of pieces unused.
	K.	*Per c't.*	*Per c't.*	*K.*	*Per c't.*	*Per c't.*
La Seyne	190, 600	0. 90	0. 52	30, 000	0. 00	0. 00
Toulon	639, 383	0. 20	0. 06	411, 235	0. 28	0. 01
Rochefort	576, 083	(*)	0. 03	(*)	(*)	(*)
Lorient	653, 669	0. 75	0. 07	842, 342	0. 52	0. 40
Brest	418, 280	0. 78	0. 00	784, 746	1. 04	0. 23
Cherbourg	227, 069	1. 24	0. 04	101, 755	3. 09	0. 00
Total	2, 705, 084	†0. 52	0. 08	†2, 170. 078	†0. 77	†0. 24

Localities.	From May 1, 1880, to November 1, 1880.			Total up to November 1, 1880.		
	Total weight of plates and bars used.	Percentage of weight.		Total weight of plates and bars used.	Percentage of weight.	
		Of pieces spoilt.	Of pieces unused.		Of pieces spoil.	Of pieces unused.
	K.	Per c't.	Per c't.	K.	Per c't.	Per c't.
La Seyne	199, 500	0.00	0.00	2, 010, 100	1.08	0.11
Toulon	535, 149	0.00	0.00	4, 051, 245	0.34	0.12
Rochefort	228, 845	(*)	0.07	1, 157, 896	(*)	†0.09
Lorient	862, 930	0.97	0.47	4, 764, 415	0.88	0.32
Brest	793, 483	0.81	0.02	3, 643, 065	0.73	0.06
Cherbourg	570, 448	0.06	0.00	1, 339, 417	0.71	0.04
Total	3, 190, 351	†0.47	0.14	†16, 962, 138	†0.67	†0.15

* No information.
† Excluding the quantities now at Rochefort, but not returned.

APPENDIX A.

Classification of plates, angles, and rolled bars in steel.—Instructions relating to their employment, and to the tests they have to undergo.—(Ministerial circular of the 11*th May,* 1876.)

Steel Plates.

CLASSIFICATION BY SIZE.

The limiting sizes of plates to be ordered are stated in the table below, in which the plates are classified according to their area in five sets. The plates of the first class will command the price marked in the eontracts, those of the four other classes will bear this same cost increased respectively by two, four, six, and eight francs per hundred kilograms.

RECTANGULAR PLATES ABOVE 400 MILLIMETRES WIDE.

Thickness in millimeters.	Maximum length in meters.	Maximum breadth in meters.	Maximum area in square meters.				
			First class.	Second class.	Third class.	Fourth class.	Fifth class.
1½	3.75	1.20	....	2.00	2.75	3.25	....
2	4.00	1.30	....	2.50	3.00	3.50	....
2½	4.75	1.30	2.50	2.75	3.25	3.75	....
3	7.00	1.50	2.50	3.25	4.00	4.75	5.75
4	7.50	1.50	3.00	3.75	4.50	5.00	6.00
5	8.00	1.60	3.50	4.50	5.00	5.50	6.60
6	9.00	1.80	3.75	4.75	5.25	5.75	7.00
7	10.00	2.00	4.50	5.25	6.00	6.50	7.50
8	10.00	2.00	4.75	5.75	6.50	7.00	8.00
9, 10, 11	10.00	2.00	4.50	5.50	6.50	7.50	9.00
12, 13	10.00	2.00	3.75	4.75	5.50	6.50	8.00
14, 15	10.00	2.00	3.25	4.25	5.25	6.00	7.50
16, 17, 18	8.00	2.00	2.50	3.25	4.25	5.50	7.00
19, 20, 21	6.50	1.85	2.25	2.75	3.75	4.75	....
22, 23	6.00	1.85	2.00	2.75	3.75	4.75	....
24, 25	6.00	1.60	2.00	2.50	3.50	4.50	....
26 to 30	6.00	1.40	2.00	2.50	3.00	4.00	....

STRAPS AND BUTT STRAPS.

Thickness in millimetres.	Maximum length in meters.	Breadth in centimeters.	Maximum area in square meters.			
			First class.	Second class.	Third class.	Fourth class.
From 5 to 8	10.00	10 to 40	2.00	2.75	3.50	4 00
From 9 to 13	10.00	10 to 40	2.75	3.50	4.00	....
From 14 to 20	10.00	15 to 40	2.00	3.00	4.00	..... .
From 20 to 30	10.00	20 to 40	2.60	2.60	3.00	4 00

Plates may also be ordered which are not rectangular, but have straight sides. Their class will be determined by the area of the smallest rectangle which can be circumscribed to them. The cost of these plates will be three francs more per hundred kilograms than the rectangular plates of the same class.

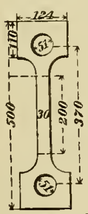
All plates not comprised in the above classification will be subject to special bargain.

TESTS FOR ACCEPTANCE.

To make sure of the quality of steel plates they shall be subjected to three kinds of tests; cold tests, hot tests, and tests of temper.

(1) COLD TESTS.—The object of these tests will be to determine the tensile strength and the elongation of the metal, both in the direction of rolling and at right angles to it. The mean results both of tensile strength and of elongation obtained in each of these two directions will be separately tested by means of five trials at least for each.

For these tests, test pieces shall be cut from a certain number of sheets taken by chance in each delivery, taking care to test for each sheet an equal number of pieces in



the direction of rolling and in that at right angles to it. These pieces shall be fashioned so as to have for their section a rectangle of which one of the sides shall be 30 millimetres wide, and the other shall be the thickness of the plate. Nevertheless, for thin plates below 5 millimetres, the width of the test piece shall be reduced to 20 millimetres, and, for plates of 18 millimetres thickness and above, the breadth may be reduced to the thickness of the plate. The length of the prismatic portion submitted to the test for tensile strength shall always be exactly 20 centimetres. These test pieces shall in no case be annealed.

The test pieces shall be, by means of a weight acting directly in the direction of their length, or by means of levers carefully adjusted, submitted to tensile loads increasing until they break. These loads shall never be calculated from the indications of the pressure-gauge, if the machine used to produce them includes a hydraulic press. The initial load shall be determined in such a manner as to produce a tension equal to eight-tenths of the breaking load, calculated according to the following table. The first load shall be kept in continuous action for five minutes. The additional loads shall then be added at intervals of time as nearly as possible equal to one another, and separated by half a minute; they shall be calculated as nearly as possible at half a kilogram of load for each square millimetre of the section of the bar to be broken. A note must be taken for each load of the corresponding elongation, measured upon the original prismatic length of 20 centimetres. The final elongation shall be that produced under tension at the moment of breaking.

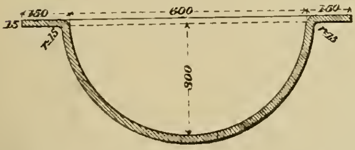
No test piece accepted as sound must break under the initial load, nor give a final elongation of less than eight-tenths of the mean final elongation required. Narrow plates, which will not permit of test pieces being cut in the transverse direction, are only to be tried in the direction of length, that is to say, in the direction of rolling.

The mean minimum loads per square millimeter of the original section under which the test pieces may be expected to break, and the corresponding mean minimum elongation, are given in the following table. For plates, the mean results which are to be compared with the figures of this table are those which shall have been obtained in the direction of least resistance.

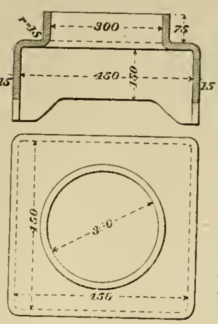
Thickness in millimetres.	Steel plates.			
	For ships.		For boilers.	
	Mean load (minimum).	Mean final elongation (minimum).	Mean load (minimum).	Mean final elongation (minimum).
	Kilo's.	*Per ct.*	*Kilo's.*	*Per ct.*
1½	47	10	....	....
2 to 3 exclusive	47	12	....	....
3 to 4 exclusive	47	14	....	....
4 to 5 exclusive	46	16	....	....
5 to 6 exclusive	46	18	....	....
6 to 8 exclusive	45	20	42	25 *[24]
8 to 20 exclusive	45	20	42	26
20 to 30 inclusive	44	20	40	25
	Straps and butt straps.			
	Along.		Across.	
	Kilo's.	*Per ct.*	*Kilo's.*	*Per ct.*
4 to 6	48	18	44	16
6 to 16	48	22	44	18
16 to 30	48	22	42	17

* Corrected in supplementary dispatch of 7th May, 1877, given hereafter.

(2) Hot tests.—The test will consist in hammering out of a piece of plate of suitable dimensions, a hemispherical cup, with a flat rim left in the original plane of the plate. The diameter of the hemisphere, measured on its inside, is to be equal to forty times the thickness of the plate, and the flat circular rim is to have for its width ten times this thickness. This flat rim is to join on to the spherical part by a bend, of which the radius, measured on the inside of the angle, shall be, at most, equal to the thickness of the plate.



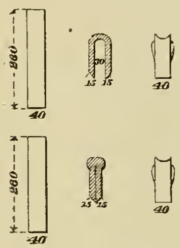
Besides this, for plates of more than five millimetres in thickness there shall be made a box with a square base, with the sides at right angles to the plane of the plate, the base of this box shall have for its side thirty times the thickness of the plate, and the raised rims shall have for their height ten times this thickness.



The bottom of this box shall be pierced in the middle with a circular hole, with a rim raised perpendicularly to the bottom, and on the opposite side to that of the rim of the box. The diameter of this hole, measured on its inside, after the work is done, shall be twenty times the thickness of the plate, and the height of the rim shall be five times this thickness. All the angles shall be rounded, their internal bend having for radius the thickness of the plate.

The test pieces thus made with all the precautions required in working steel must present neither flaws nor cracks even after being cooled in a strong current of air.

(3) Temper tests.—For these tests there must be cut from the lots of plates presented for acceptance bars of 26 centimetres in length by 4 centimetres thick, both in the direction of rolling and in the transverse direction; nevertheless, these test pieces shall be cut in the direction of rolling only when it is necessary to test straps or butt straps of less than 26 centimetres wide. These bars shall be uniformly heated to a dark cherry red, and then plunged into water at 28° Centigrade. Thus prepared it must be possible to give them, under the press, without their showing any sign of breaking, a permanent bend, of which the minimum internal radius shall not exceed the thickness of the bar tested.



These same bars, when taken from boiler-plates, must be capable under the action of the press of being doubled up flat, so that the two halves shall be completely in contact with one another, and this without presenting any trace of cracking.

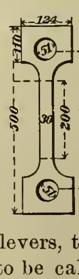
N. B.—Bars prepared for these temper tests must not have their sheared sides rounded off, the only treatment permitted will be to take off the sharpness of the edges with fine file.

The plates which do not satisfy the conditions detailed above must be rejected.

ANGLES, BULB BARS, T-BARS OR TT-BARS IN STEEL.

To determine the quality of these various sorts of rolled bars there shall be three series of tests made; cold tests, temper tests, hot tests.

(1) Cold tests.—The object of these tests will be to determine the tensile strength and the elongation of the metal. For this purpose there must be cut out from the webs of a certain number of bars taken by chance in each delivery test pieces fashioned so as to have as nearly as possible a rectangular transverse section. The thickness of these test pieces shall be that of the webs of the steel tested; their breadth shall be 30 millimetres. Nevertheless, for all webs less than 5 millimetres thick, this breadth shall be reduced to 20 millimetres, and, for all those less than 18 millimetres thick, this dimension may be reduced to the thickness of the web. The length of the prismatic portion subjected to tension shall be exactly 20 centimetres. The test pieces are in no case to be annealed. These test pieces shall be submitted, by means of a weight acting directly, or through a series of carefully adjusted levers, to a tensile force increasing until breakage takes place. The loads are not to be calculated from the indications of the pressure gauge, if the machine used to produce them includes a hydraulic press. The initial load shall be determined so as to produce a tension equal to eight-tenths of the breaking stress calculated from the following table. This first load shall be kept at work for five minutes. The additional loads



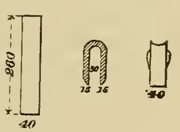
shall then be added at intervals of time as nearly as possible equal, and about half a minute apart. They will be calculated, as nearly as possible, in the ratio of half a kilogram of tension for each square millimetre of the section of the bar to be broken. A note shall be taken for each load of the corresponding elongation measured on the primitive length of 20 centimetres. The final elongation shall be that produced under tension at the moment of breaking. No test piece accepted as sound must break under the initial load, nor give a final elongation less than eight-tenths of the mean final elongation required.

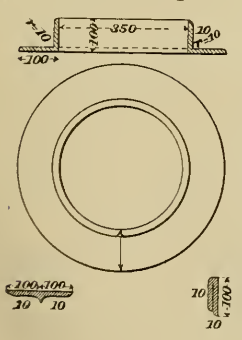
The mean minimum loads per square millimetre of the original section under which the test bars may be expected to break, and the corresponding mean elongations, are given in the following table, the pull for the molded steel bars being always in the direction of rolling:

Thickness of webs in millimeters.	Angles and bulb bars.		Single T bars.		Double T, bulb, and bulb T bars.	
	Mean load (minimum).	Mean final elongation.	Mean load (minimum).	Mean final elongation.	Mean load (minimum).	Mean final elongation.
	Kilo's.	*Per ct.*	*Kilo's.*	*Per ct.*	*Kilo's.*	*Per cent.*
From 3 to 4	48	18	48	18	46	16
From 4 to 6	48	20	48	20	46	16
From 6 to 16	48	22	48	20	46	18
From 16 to 25	48	20 *[22]	48	20	46	18

* See correcting circular of 7th May, 1877.

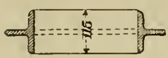
(2) Temper tests.—For these tests there shall be cut from the webs of the bars presented for acceptance strips of 26 centimeters long and 40 millimeters wide. The sheared sides of these strips are not to be rounded, the only treatment permitted will be to take off the sharpness of the edges by means of a fine file. The bars shall then be uniformly heated to a dark cherry red, and then dipped in water at a temperature of 28° Centigrade. Thus prepared they must be able to take under the action of the press a permanent bend, the radius of which, measured on the inside, must not exceed one and a half times the thickness of the bar tested.





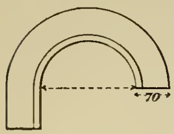
(3) Hot tests.—Angle-irons shall be submitted to the following tests: A piece shall be cut from the end of an angle-iron taken by chance from each delivery, and this shall be bent into a ring, so that one of the sides of the angle-iron shall be kept flat, the other side forming a cylinder, of which the internal diameter shall be equal to three and a half times the breadth of the side which remains flat. Another piece taken from another bar shall be opened out until the two interior faces shall be practically in the same plane. A third piece cut from a third bar shall be closed until the two sides touch.

The angle-irons submitted to these tests must show neither cracks, clefts, nor flaws.

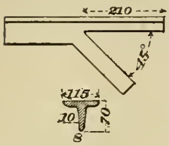


Single T-bars shall be submitted to the following tests:

A piece shall be taken from the end of a bar selected by chance in each delivery, and it shall be bent into a half ring, so that, the web remaining in its own plane, the cross flange shall form a half cylinder, of which the internal diameter shall be equal to four times the height of the web of the T-bar.

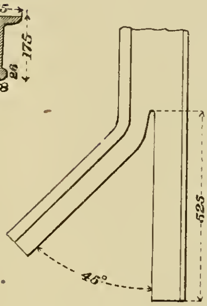


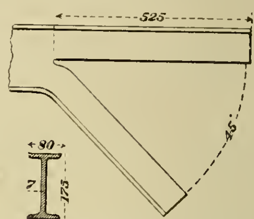
At the end of another bar selected by chance from the same delivery the web shall be split down its middle for a length equal to three times the total depth of the bar, and a hole shall be drilled at the end of the slit to prevent its spreading; the piece thus separated shall be opened out in its own plane so as to make an angle of 45° with the rest. Care must be taken that the part opened out shall be kept straight, except that it must be joined to the rest of the bar by a bend of small radius.



The bars subjected to these tests must show neither cracks, clefts, nor flaws.

Bulb, bulb T, and TT bars are to be submitted to the following tests:





At the end of a bar selected by chance in each delivery the central web shall be split down the middle for a length equal to three times the total depth of the web, and a hole shall be drilled at the end of this slit to prevent its spreading; then one of the two sides shall be opened out at one or more heats so as to keep the central web flat in its own plane, and to bring the two pieces to make an angle of 45° with one another; for bulb and bulb T irons the side to be bent will be that which carries the bulb. Care must be taken to keep the portion opened out practically straight, with the exception that it must be joined to the rest of the bar by means of a bend of low radius.

The bars subjected to these tests must show neither cracks, clefts, nor flaws.

Angles and molded bars which do not satisfy these conditions are to be rejected.

Corrections to the Ministerial Circular of the 11th May, 1876, relating to the classification and tests of plates, angles, and molded bars in steel.—(Ministerial Circular of the 7th May, 1877.)

The experience which has been had of the circular of the 11th May, 1876, relating to the classification and tests of plates, angles, and molded bars in steel has shown that it would be useful to make the following corrections in the figures inserted in the tables:

1st. In the table giving the breaking stresses and the corresponding elongations for plates, to reduce from 25 to 24 per cent. the elongation required in boiler plates of 6 to 8 millimeters in thickness.

2d. In the table relating to the breaking strains and elongations of molded bars, to increase from 20 per cent. to 22 per cent. the elongation of angles and bulb irons of 16 to 25 millimeters thick.

New classification of plates, angles, and molded bars in iron. Instructions respecting their use, and the tests to which they are to be subjected (added for the sake of comparison).—(Ministerial Circular of the 17th February, 1868.)

IRON PLATES.

The custom of the trade distinguishes bars and plates into four principal qualities, viz: Common iron, strong iron, best strong iron, fine, or charcoal iron.

These four qualities doubtless vary from one forge to another, and there are intermediate qualities to them. But these are the kinds most generally distinguished, and of which the specification understood by all can give rise to no misunderstanding, and they are sufficient for all the ordinary needs of the trade.

This same classification has accordingly been adopted for the Navy, fixing as follows in a general way their use in each division:

First Class.—Common plates. Trade name, best common iron plates: Funnels, bulkheads, deck plates, coal bunkers, galleys, flooring plates, small iron plate work, barges, and other similar vessels.

Second Class.—Ordinary plates. Trade name, strong iron plates: Outside plating, floor plates, plates for deck beams, boiler shells, inner linings.

Third Class.—Superior plates. Trade name, best strong iron plates: Fronts of boilers, bottoms of boilers, steam chests, superheaters, ash boxes, forged parts of land boilers, garboards, scuppers.

Fourth Class.—Fine plates. Trade name, wrought-iron plates and charcoal-iron plates: Tube plates for boilers, boiler hearths, fire boxes, smoke boxes, smoke flues.

This distribution only gives the principal uses of the different classes of plates, and consequently leaves it open to engineers to settle, by keeping as close to it as possible, in what class they are to place uses which are not mentioned in it. The preceding classification must not even be regarded as absolute with reference to the uses named in it. Thus, to give an example, the barges mentioned in the first class are to be built of common plates; nevertheless certain barges have knee strakes, and fashioned stem and stern pieces, for which the use of *common* plates is not suited. For these pieces the use of *ordinary* plates is by way of analogy indicated.

The addition of the third class corresponding to best strong iron will permit the conditions of acceptance of ordinary plates to be slightly reduced, and will furnish a superior quality for certain work which cannot be safely executed with ordinary plate. As to angle-irons, the quality called "fine" or "best best" may be neglected, charcoal angle-irons being no better in practice than those made with best strong iron. Angle-irons will accordingly be divided into—

Ordinary angles.—Trade name, welded iron angles: For hulls, deck beams, and such work.

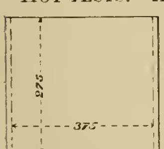
Best angles.—Trade name, best strong iron angles: For boilers.

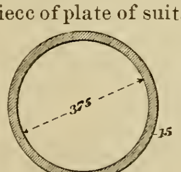
Finally T-irons and T T-irons will be classified as of *ordinary* quality for deck beams, and of *common* quality for land structures.

COMMON PLATES.

For testing plates two sorts of tests shall be applied, hot and cold.

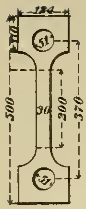
HOT TESTS.—A piece of plate of suitable dimensions shall be cut from a plate selected





by chance in each delivery, and this shall be worked into a cylinder, having both for its height and for its internal diameter twenty times the thickness of the plate. This cylinder, wrought with suitable care, must show neither cracks nor flaws. This test shall be applied to plates of every different thickness; it may be applied more than once if thought necessary by the receiving officers.

COLD TESTS.—These tests will consist in determining the tensile strength of plates



and their elongation both in the direction of rolling, as well as in the transverse direction. The mean coefficients of tensile strength and of elongation shall be separately determined in both these directions by means of at least five tests for each of them.

In the direction which shall give the least resistance, the mean breaking load per square millimeter of section shall be at least 28 kilograms, and the mean corresponding elongation shall be at least $3\frac{1}{2}$ per cent. Besides this, each separate proof applied to a bar which has been recognized as sound, must give a breaking load of not less than 25 kilograms per square millimeter, and an elongation of not less than $2\frac{1}{2}$ per cent. For these tests strips must be cut from a certain number of plates selected by chance in each delivery, taking care to test for each plate an equal number of strips in the direction of rolling and in the transverse direction. These strips must be fashioned so as to have for their breaking section a rectangle, of which one of the sides shall be 30 millimeters wide, and the other shall be the thickness of the plate; except that for thin plates below 5 millimeters in thickness, the width of the test piece shall be reduced to 20 millimeters. The length of the prismatic part subject to tensile stress shall always be 20 centimeters.

These strips shall be submitted by means of weights acting directly or through levers adjusted with care, to tensile loads increasing until they break.

The initial load shall be calculated so as to produce a tensile stress of 25 kilograms per square millimeter of section; this first load shall be kept at work for five minutes. The additional loads shall then be imposed at equal intervals of time, about a minute apart. These additions shall be arranged, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for a square millimeter of section.

For each load shall be noted the corresponding elongation, measured upon the prismatic length of 20 centimeters.

When plates presented for acceptance shall be of more than 5 meters long and less than 50 centimeters wide the means of the results obtained must not fall below the following figures:

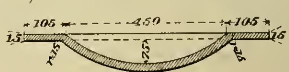
	Along.	Across.
Breaking stress per square millimeter of section	32 K.	26 K.
Corresponding elongation, per cent	6	2.5

The deliveries which do not satisfy these conditions must be rejected.

ORDINARY PLATES.

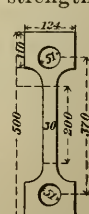
To test the quality of plates, two kinds of tests shall be applied, hot and cold.

HOT TESTS.— A piece of plate of suitable dimensions, cut from a sheet selected by chance in each delivery, shall be wrought into a spherical cup, with a flat rim, the rim being in the original plane of the plate. The diameter of this cup,



measured on the inside, shall be equal to thirty times the thickness of the plate, and its depth, also measured on the inside, shall be equal to five times this thickness. The width of the circular rim shall be seven times the thickness of the plate, and it shall join the spherical part by a bend, having for radius the thickness of the plate. The radius of this bend shall be measured on the inside of the angle. The cup thus wrought with all necessary precautions must show neither cracks nor flaws. This test shall be applied to plates of every different thickness; it may be applied more than once if the receiving officers consider it necessary.

COLD TESTS.—The object of these tests will be to determine the tensile strength of the plates and their elongation, both in the direction of rolling and in the transverse direction.



The mean results of tensile strength and elongation in each of these directions shall be separately established by means of at least five tests in each direction.

In the direction which gives the least resistance, the mean breaking load per square millimeter of section must be at least 31 kilograms, and the corresponding elongation at least 5 per cent. Moreover, each separate test applied to a strip, which has been recognized as sound, must give a result of at least 28 kilograms per square millimeter, and an elongation of at least 4 per cent.

For these tests strips of plate must be cut from a certain number of plates, selected by chance in each delivery, taking care to test for each plate an equal number of strips in the direction of rolling and transversely to it. These strips must be fashioned so as to have for their breaking section a rectangle, of which one of the sides must be 30 millimeters wide, and the other side the thickness of the plate; except that for thin plates of less than 5 millimeters thick, the breadth of the test strip is to be reduced to 20 millimeters. The length of the prismatic portion submitted to the test must always be 20 centimeters.

These strips will be submitted, by means of weights acting directly or through levers carefully adjusted, to tensions increasing until they break.

The initial load must be calculated so as to produce a load of 28 kilograms per square millimetre of section; this first load is to be kept at work for five minutes. The additional loads are then to be imposed at equal intervals of time about a minute apart. They shall be adjusted as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimetre of section.

A note shall be taken for each load of the corresponding elongation, measured on the prismatic length of 20 centimetres.

When the plates presented for acceptance are strips for beams, tie plates, carlings, coamings, sheer-strakes, water-ways, keelsons, and stringers of more than 5 metres long and less than 50 centimetres wide, the means of the results obtained in each direction must not fall below the following figures:

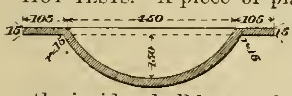
	Along.	Across.
Breaking stress per square millimeter of section	34 K.	28 K.
Corresponding elongation, per cent	9	3.5

The deliveries which do not satisfy these conditions must be rejected.

SUPERIOR PLATES.

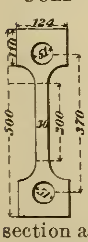
To test the quality of plates two kinds of tests shall be applied, hot and cold.

HOT TESTS.—A piece of plate of suitable dimensions, cut from a sheet selected by chance in each delivery, shall be wrought into a spherical cup with a flat rim, the rim being in the original plane of the plate. The diameter of this cup, measured on the inside, shall be equal to thirty times the thickness of the plate, and its depth, also measured on the inside, shall be equal to ten times this thickness. The width of the circular rim shall be seven times the thickness of the plate, and it shall join the spherical part by a bend having for radius the thickness of the plate. The radius of this bend shall be measured on the inside of the angle. The cup thus wrought with all necessary precautions must show neither cracks nor flaws.



This test shall be applied to plates of every different thickness; it may be applied more than once if the receiving officers consider it necessary.

COLD TESTS.—The object of these tests will be to determine the tensile strength of the plates, and their elongation both in the direction of rolling and in the transverse direction. The mean results of tensile strength and elongation in each of these directions shall be separately established by means of at least five tests in each direction. In the direction which gives the least resistance the mean breaking stress per square millimeter of section must be at least 32 kilograms, and the corresponding elongation at least 7 per cent. Moreover, each separate test applied to a strip which has been recognized as sound must give a result of at least 29 kilograms per square millimeter of section and an elongation of at least 5½ per cent.



For these tests strips of plate must be cut from a certain number of plates selected by chance in each delivery, taking care to test for each plate an equal number of strips in the direction of rolling and transversely to it. These strips must be fashioned so as to have for their breaking section a rectangle of which one of the sides must be 30 millimeters wide and the other side the thickness of the plate; except that for thin plates of less than 5 millimeters thick the breadth of the test strip is to be reduced to 20 millimeters. The length of the prismatic portion submitted to the test must always be 20 centimeters.

These strips will be submitted by means of weights acting directly or through levers adjusted with care to tensions increasing until they break. The initial load must be calculated so as to produce a strain of 29 kilograms per square millimeter of section; this first load is to be kept at work for five minutes. The additional loads are then to be imposed at equal intervals of time about a minute apart. They shall be adjusted, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimetre of section.

A note shall be taken for each load of the corresponding elongation measured on the prismatic length of 20 centimetres.

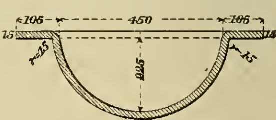
The deliveries which do not satisfy these conditions must be rejected.

FINE PLATES.

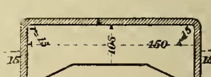
Although the national iron works of La Chaussade are bound to supply the wants of dock-yards and other naval establishments with fine plates, it has been thought necessary to specify here the tests to which these plates are to be subjected in order that the tests may be applied to this description of plates for the construction of steam boilers, the making of which is intrusted to the private trade.

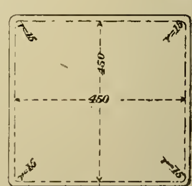
To test the quality of plates two kinds of tests shall be applied, hot and cold.

Hot tests.—A piece of plate of suitable dimensions, cut from a sheet selected by chance in each delivery, shall be wrought into a spherical cup with a flat rim, the rim being in the original plane of the plate. The diameter of this cup measured on the inside, shall be equal to thirty times the thickness of the plate, and its depth, also measured on the inside, shall be equal to fifteen times this thickness. The width of the circular rim shall be seven times the thickness of the plate, and it shall join the spherical part by a bend having for radius the thickness of the plate. The radius of this bend shall be measured on the inside of the angle. The cup thus wrought with all necessary precautions must show neither cracks nor flaws.



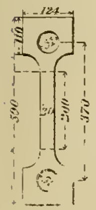
Besides this, there shall be made, from a second piece of plate taken from the same or another sheet, a box with a square bottom, with the sides at right angles to the plane of the plate. The bottom of this box shall have for its side thirty times the thickness of the plate, and the raised rims, measured on the inside, shall have for their height seven times this thickness. The rims shall join on to one another and to the bottom with a curve of which the radius, measured on the inside of the box, shall be equal to the thickness of the plate. The box thus executed must show neither cracks, flaws, nor traces of imperfect welding.





These two tests shall be applied to plates of every different thickness; they shall be applied more than once if the receiving officers consider it necessary.

Cold tests.—The object of these tests will be to determine the tensile strength of the plates and their elongation, both in the direction of rolling and in the transverse direction. The mean results of tensile strength and elongation in each of these directions shall be separately established by means of at least five tests in each direction. In the direction which gives the least resistance the mean breaking load per square millimetre of section must be at least 35 kilograms, and the corresponding elongation at least 10 per cent. Moreover, each separate test applied to a strip which has been recognized as sound must give a result of at least 30 kilograms per square millimetre of section, and an elongation of at least 7½ per cent.



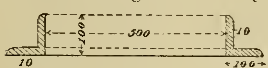
For these tests strips of plate must be cut from a certain number of plates selected by chance in each delivery, taking care to test for each plate an equal number of strips in the direction of rolling and transversely to it. These strips must be fashioned so as to have for their breaking section a rectangle of which one of the sides must be 30 millimetres wide, and the other side the thickness of the plate; except that for thin plates of less than 5 millimetres thick the breadth of the test strip is to be reduced to 20 millimetres. The length of the prismatic portion submitted to the test must always be 20 centimetres. These strips will be submitted by means of weights acting directly, or through levers carefully adjusted, to tensions increasing until they break. The initial load must be calculated so as to produce a strain of 29 kilograms per square millimetre of section. This first load is to be kept at work for five minutes, the additional loads are then to be imposed at equal intervals of time and about a minute apart. They shall be adjusted as nearly as the weights in use will permit at the rate of a quarter of a kilogram of tension for each square millimetre of section. A note shall be taken for each load of the corresponding elongation measured on the prismatic length of 20 centimetres.

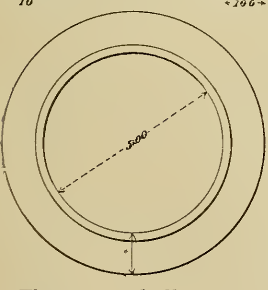
The deliveries which do not satisfy these conditions must be rejected.

ORDINARY ANGLES.

To determine the quality of iron angles, there shall be made two kinds of tests, hot tests and cold tests.

Hot test.—A piece cut off an angle iron bar, taken by chance in each delivery, shall be wrought into a cylindrical ring, so that one of the sides of the angle iron shall remain in the plane perpendicular to the axis of the cylinder formed by the other side. The internal diameter of this cylinder shall be equal to five times the breadth of the side which remains flat. Another piece cut from another bar shall be opened out until the angle formed by the two exterior faces of the sides shall be 135°. A third piece cut from a third bar shall be closed until the angle formed by the two exterior faces of the sides shall be 45°.

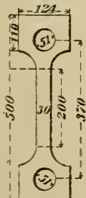




The pieces thus tried must show neither cracks, clefts, traces of longitudinal splitting, nor any other proof of imperfect welding.

These tests shall be repeated as many times as the receiving officers may consider useful.

Finally, the receiving officers must satisfy themselves that the angle irons presented for acceptance weld easily, and yield good welds.



Cold tests.—The object of these tests will be to determine the tensile strength of the iron and its elongation. For this purpose there must be cut from the webs of a certain number of bars taken by chance in each delivery, some flat strips which shall be fashioned in such a manner as to have a breaking section as nearly as possible rectangular; the thickness of these shall be that of the webs of the angle irons, their breadth shall be 30 millimetres for all angle irons having a width of more than 5 centimetres, and 20 millimetres for all those of less dimensions. The length of the prismatic portion subjected to tension shall be exactly 20 centimetres. These strips shall be submitted by means of weights acting directly or through levers carefully adjusted to a tensile force increasing until breakage takes place. The initial load shall be calculated so as to produce a strain of 30 kilograms per square millimetre of section.*

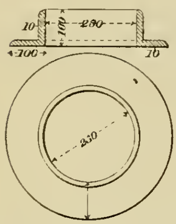
The additional loads are then to be imposed at equal intervals of time, and about a minute apart. They shall be adjusted, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimeter of section. A note shall be taken for each load of the corresponding elongation, measured on the prismatic length of 20 centimetres. The means of the results obtained by these trials, to the number of at least six for each delivery, must not fall below the following figures:

Breaking strain per square millimetre of section.................... 34 kilograms.
Corresponding elongation.. 9 per cent.

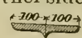
The deliveries which do not satisfy these conditions must be rejected.

BEST ANGLES.

To determine the quality of these angle irons there shall be made two kinds of tests, hot tests and cold tests.



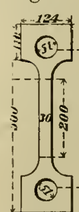
HOT TESTS.—A piece of angle iron from a bar, selected by chance in each delivery, shall be wrought into a cylindrical ring, so that one of the sides of the angle iron shall remain in the plane perpendicular to the axis of the cylinder formed by the other side. The internal diameter of this cylinder shall be equal to two and a half times the breadth of the side which remains flat. Another piece cut from another bar shall be opened out until the two exterior faces are practically in the same plane. A third piece cut from a third bar shall be closed until the two faces are in contact.



The pieces thus tested must show neither cracks, clefts, traces of longitudinal splitting, nor any other proof of imperfect welding. These tests shall be repeated as many times as the receiving officers may consider useful.

Finally, the receiving officers will satisfy themselves that the angles presented for acceptance weld easily and yield good welds.

COLD TESTS.—The object of these tests will be to determine the tensile strength of the iron and its elongation. For this purpose there must be cut from the webs of a certain number of bars, taken by chance in each delivery, some flat strips, which shall be fashioned in such a manner as to have a breaking section as nearly as possible rectangular; the thickness of these strips shall be that of the webs of the angle irons, their breadth shall be 30 millimetres for all angle irons having a width of more than 5 centimetres, and of 20 millimetres for all those of less dimensions. The length of the prismatic portion subjected to tension shall be exactly 20 centimetres. These strips shall be submitted, by means of weights acting directly, or through levers carefully adjusted, to a tensile force increasing until breakage takes place. The initial load shall be calculated so as to produce a strain of 32 kilograms per square millimetre of section. No test piece accepted as sound must break under this load (which shall be kept in action for five minutes), nor give an elongation of less than 9 per cent. of its original length.



The additional loads are then to be imposed at equal intervals of time, and about a minute apart. They shall be adjusted, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimetre of section. A note shall be taken for each load of the corresponding elongation, measured on the

* Explained in supplementary circular of 20th October, 1873, given hereafter.
No test piece accepted as sound must break under this load (which shall be kept in action for five minutes), nor give an elongation of less than 6 per cent. of its original length.

prismatic length of 20 centimetres. The means of the results obtained by these trials, to the number of at least six for each delivery, must not fall below the following figures:

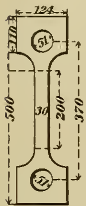
Breaking strain per square millimetre of section .... 35 kilograms.
Corresponding elongation .... 12 per cent.

The deliveries which do not satisfy these conditions must be rejected.

T-IRONS AND DOUBLE T-IRONS OF COMMON QUALITY.

To determine the quality of the irons presented for acceptance, they will be submitted to tests of tension.

For this purpose there shall be cut from the webs of a certain number of bars, taken by chance in each delivery, and in the direction of rolling, some flat strips, which shall be fashioned so as to have a section as nearly as possible rectangular. The thickness of these shall be that of the webs of the bars; their breadth shall be 30 millimetres for all webs having a thickness of more than 5 millimetres, and of 20 millimetres for those of a less thickness. The length of the prismatic portion subjected to tension shall be exactly 20 centimetres. These strips shall be submitted, by means of weights acting directly or through levers carefully adjusted, to tensions increasing until they break.



The initial load shall be calculated so as to produce a tensile force of 28 kilograms per square millimetre of section. No strip accepted as sound must break under this load (which shall be kept in action for five minutes), nor give an elongation of less than 3½ per cent. of its original length. The additional loads shall then be imposed at intervals of time practically equal and about one minute apart. These loads shall be adjusted, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimetre of section.

A note shall be taken for each load of the corresponding elongation measured on the prismatic length of 20 centimetres. The means of the results obtained by these trials, to the number of at least six for each delivery, must not fall below the following figures:

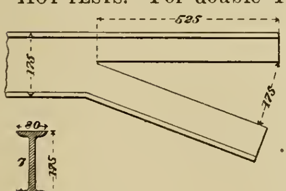
Minimum breaking strain per square millimetre of section .... 32 kilograms.
Corresponding elongation .... 6 per cent.

The deliveries which do not satisfy these conditions must be rejected.

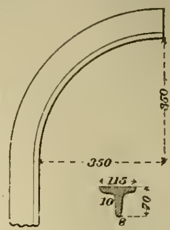
T-IRONS AND DOUBLE T-IRONS OF ORDINARY QUALITY.

In order to determine the quality of T-irons and double T-irons presented for acceptance, there shall be made two kinds of tests, hot tests and cold tests.

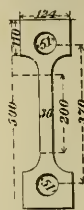
HOT TESTS.—For double T-irons a bar selected by chance in each delivery must first be split cold by means of a shearing machine, in the direction of its length, right along the middle of the web, for a length equal to three times the depth of the web, and a hole shall be drilled at the end of the cut, so as to prevent its spreading. Then by forging it hot, one half must be opened out from the other, until the distance between the two portions of the web, measured at the end, shall be equal to the whole depth of the double T-bar.



For single T-bars, the end of the bar chosen for testing is to be forged, so that while the web remains in its own plane, the bar shall be wrought into a quadrant of a circle, with the flange inside, whose radius measured internally shall be equal to five times the total depth of the T-bar.



COLD TESTS.—There shall be cut from the webs or flanges of a certain number of bars taken by chance in each delivery, and in the direction of rolling, some flat strips which shall be fashioned in such a manner as to have a section as nearly as possible rectangular. The thickness of these shall be that of the webs, their breadth shall be 30 millimetres for all webs having a thickness of more than 5 millimetres, and 20 millimetres for all those of less thickness. The length of the prismatic portion subjected to tension shall be exactly 20 centimetres. These strips shall be submitted by means of weights acting directly, or through levers carefully adjusted to a tensile force increasing until they break. The initial load shall be calculated so as to produce a strain of 30 kilograms per square millimetre of section. No strip accepted as sound must break under this load (which shall be kept in action for five minutes), nor give an elongation of less than 6 per cent. of its original length. The additional loads are then to be imposed at equal intervals of time and about a minute apart. These loads shall be adjusted, as nearly as the weights in use will permit, at the rate of a quarter of a kilogram of load for each square millimetre of section. A note shall be taken for each load of the corresponding elongation, measured on the prismatic length of 20 centimetres. The means of the results obtained by these trials, to the number of at least six for each delivery, must not fall below the following figures:



Minimum breaking strain per square millimetre of section............. 34 kilograms.
Corresponding elongation.. 9 per cent.

The deliveries which do not satisfy these conditions must be rejected.

Interpretation to be given to a paragraph in the circular of the 17*th February*, 1868, *relating to the tests of angle irons.—(Ministerial Circular of* 20*th October*, 1873.)

Something which recently took place in the acceptance of angle irons seems to require that certain additional explanations should be given as to the interpretation of the paragraph in the circular of the 17th February, 1868 (see above, page 125), which is as follows: "No test-piece accepted as sound must break under this load (30 kilograms), nor must give an elongation of less than 6 per cent. of its original length."

It might be understood in reading this paragraph that with an initial load of 30 kilograms per square millimetre of section, the bar ought to stretch 6 per cent., and that therefore angle irons which did not show this elongation ought to be rejected. This is not the meaning intended.

The object of the circular quoted above was to impose the double condition that no isolated test should give a breaking stress of less than 30 kilograms, nor an elongation upon breaking of less than 6 per cent. The corresponding article relating to the various classes of plates was intended to have the same meaning.

Modification of the tests of plates, angle irons, and rolled bars of iron.—(Ministerial Circular of 6*th March*, 1874.)

The ministerial circular of the 17th February, 1868, has received various interpretations, to which official attention has been drawn. These involve the following four questions:

First. What is the number of hot or cold tests to be applied to the plates or bars included in each lot presented for acceptance?

Secondly. Are the results obtained with unsound strips to enter into the calculation of the means?

Thirdly. The discovery in a strip of faults sufficient for its rejection: ought it to lead to the rejection of the plate from which this strip has been cut?

Fourthly. Is it not advisable to introduce certain modifications into the conditions of acceptance of fine plates?

The solutions of these questions depend on the following considerations:

First. The circular of the 17th February, 1868, prescribes that plates of all different thicknesses shall be subjected to the test of working a spherical cup, seeing that this condition was then applied to previous purchases for stores, including for each thickness of plates a pretty large order. But in the present contracts entered into with reference to specific work, this condition becomes expensive for the navy. It leads, in fact, very often to sacrificing a plate out of a small lot of plates; it obliges the tests, and consequently the waste, to be increased beyond reason. The hot test must, therefore, be applied in one delivery to each separate thickness of plates only when that is seen to be necessary.

As to the cold tests, seeing that according to the terms of the circular quoted, the test strips are to be cut from plates or bars taken by chance in each delivery, it evidently follows that these plates or bars may be of different thicknesses. There is, moreover, no object in applying to each separate thickness these tests, the only object of which is to ascertain the quality of the metal, a quality which will usually vary only within very narrow limits in relation to the dimension or the shape.

Secondly. The answer to the second question is implicitly contained in the instruction of the 17th February, 1868, and it is easy to infer it from the text. We read, in fact, in each of the sections relating to the cold tests, that no strips accepted as sound must break under a load below a certain minimum weight indicated in each case, nor give an elongation less than a minimum, which is also stated. Now it appears clearly from this condition that the discovery of a bar as defective must be regarded as accidental, and that it may give, both as regards breaking stress and elongation, results inferior to the prescribed minima, without its being possible to draw from it any indication of the quality of the iron, The results furnished by such bars must not therefore be included in the calculation of the means. Moreover, when a lot of plates or bars is presented for acceptance, there are two things to be determined—the satisfactory condition of each of the sheets or bars composing the lot, and the quality of the material; thus involving two distinct operations, first, a careful examination of local faults, and secondly, a mechanical operation intended to determine the tenacity and ductility of the metal. This last operation would infallibly lead to error if executed upon specimens of which the tenacity has been affected by local and accidental defects. It ought, therefore, only to be applied to normal, that is to say, to sound specimens.

Thirdly. The third question is to be answered in the affirmative. In fact, for the plates and bars which have been used for tests, that is to say, for those from which the test pieces have been cut, the contractors have a right to charge the price if the lot tested is accepted. There is then a loss, which falls upon the navy estimates, which thus have to pay for the certainty of only accepting those lots which satisfy the conditions stated; but the plate or bar which furnished the unsound strip has been cut up, and has not supplied the expected information to the purchaser. It is thus absolutely in the condition of a sheet or bar presented for acceptance without having the necessary dimensions. This plate or bar must consequently be rejected. It must be understood that this rejection can only take place on final acceptance either in the factory or the dock-yard, the third question evidently not presenting itself in the case of the counter-tests mentioned in the circular of the 3d December, 1873.

Fourthly. After the recent experiments upon fine plates, it has been established that plates of this class have stood very well, although they have not satisfied as regards tensile strength the conditions of acceptance required by the order of the 17th February, 1868. As the retention of these conditions would have the effect of uselessly raising the prices by refusing material in reality sufficiently good, it has been decided that after the words, "in the direction which gives the least resistance, the breaking stress shall be at least 35 kilograms, and the corresponding elongation at least 10 per cent.," a paragraph should be inserted as follows: "Nevertheless the above breaking stress may be diminished by a quantity not exceeding 3 kilograms, provided this deficiency be compensated for by an excess of elongation of at least 1½ per cent. per kilogram."

Appendix B.

Results of tensile tests of plates and rolled bars made of steel, delivered at the port of Toulon between the 30th of June, 1871, and the 24th of February, 1881, for the construction of the hulls of vessels.

STEEL PLATES 1½ MILLIMETRES IN THICKNESS. Maker, B.

Summary of Results.

[The loads are given in kilograms per square millimeter.]

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	47.00	47.00	10.00	10.00
Minimum breaking strength	37.60	37.60	8.00	8.00
Obtained:				
Mean breaking strength	49.93	50.11	16.08	14.45
Maximum breaking strength	50.58	51.35	18.65	14.95
Minimum breaking strength	49.47	49.28	13.29	13.98

STEEL PLATES 3 TO 4 MILLIMETRES IN THICKNESS (EXCLUSIVE). Maker, B.

Summary of Results.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	47.00	47.00	14.00	14.00
Minimum breaking strength	37.60	37.60	11.20	11.20
Obtained:				
Mean breaking strength	48.00	48.13	20.53	21.39
Maximum breaking strength	50.50	48.60	23.00	23.40
Minimum breaking strength	45.70	47.46	16.33	19.60

STEEL PLATES 4 TO 5 MILLIMETRES IN THICKNESS (EXCLUSIVE). MAKERS, A, B, D.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	46.00	46.00	16.00	16.00
Minimum breaking strength	36.80	36.80	12.80	12.80
Obtained:				
Mean breaking strength, A	49.23	49.70	22.78	22.65
Mean breaking strength, B	47.63	47.77	20.76	20.29
Mean breaking strength, D	46.42	47.03	22.20	24.83
Maximum breaking strength, A	51.20	50.70	23.40	23.90
Maximum breaking strength, B	50.25	50.40	23.20	23.40
Maximum breaking strength, D	46.42	47.03	22.20	24.83
Minimum breaking strength, A	48.50	49.30	22.50	22.00
Minimum breaking strength, B	45.70	44.60	16.00	17.00
Minimum breaking strength, D	46.42	47.03	22.20	24.83

STEEL PLATES 5 TO 6 MILLIMTRES IN THICKNESS (EXCLUSIVE). MAKERS, A., B., D.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	46.00	46.00	18.00	18.00
Minimum breaking strength	36.80	36.80	14.40	14.40
Obtained:				
Mean breaking strength, A	48.74	49.46	22.62	22.62
Mean breaking strength, B	47.29	47.21	22.18	21.92
Mean breaking strength, D	49.69	47.53	21.60	22.09
Maximum breaking strength, A	51.20	50.70	23.40	23.90
Maximum breaking strength, B	50.25	51.60	24.18	23.50
Maximum breaking strength, D	52.75	48.08	24.03	24.15
Minimum breaking strength, A	46.80	48.50	22.00	22.00
Minimum breaking strength, B	45.66	44.60	19.70	20.00
Minimum breaking strength, D	47.52	46.55	20.25	20.62

STEEL PLATES 6 TO 20 MILLIMETRES IN THICKNESS (EXCLUSIVE). MAKERS, A., B., D.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	45.00	45.00	20.00	20.00
Minimum breaking strength.....	36.00	36.00	16.00	16.00
Obtained:				
Mean breaking strength, A......	48.38	48.20	23.44	23.22
Mean breaking strength, B......	46.53	46.60	23.13	22.02
Mean breaking strength, D......	48.34	48.18	22.47	22.46
Maximum breaking strength, A.	51.20	50.70	25.50	26.80
Maximum breaking strength, B.	50.00	50.40	26.60	25.00
Maximum breaking strength, D.	49.18	50.01	24.03	24.15
Minimum breaking strength, A.	46.60	46.00	22.00	22.00
Minimum breaking strength, B.	45.00	44.60	18.50	18.50
Minimum breaking strength, D.	47.57	47.40	21.70	21.50

STEEL PLATES 20 TO 30 MILLIMETRES IN THICKNESS (INCLUSIVE). MAKERS, B., D.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	44.00	44.00	20.00	20.00
Minimum breaking strength.....	35.20	35.20	16.00	16.00
Obtained:				
Mean breaking strength, B......	46.10	45.30	23.27	22.32
Mean breaking strength, D......	44.16	45.16	24.90	25.10
Maximum breaking strength, B.	48.50	46.15	26.50	23.75
Maximum breaking strength, D.	44.16	45.16	24.90	25.10
Minimum breaking strength, B..	44.22	44.60	21.73	20.47
Minimum breaking strength, D..	44.16	45.16	24.90	25.10

STEEL STRAPS FROM 4 TO 6 MILLIMETRES IN THICKNESS (EXCLUSIVE). MAKER, B.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	48.00	44.00	18.00	16.00
Minimum breaking strength.....	38.40	35.20	14.40	12.80
Obtained:				
Mean breaking strength.........	47.74	45.90	21.90	22.47
Maximum breaking strength	49.55	47.00	23.50	23.90
Minimum breaking strength.....	46.64	44.60	21.25	20.47

TEEL STRAPS FROM 6 TO 16 MILLIMETRES IN THICKNESS (EXCLUSIVE). MAKER, B.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	48.00	44.00	22.00	18.00
Minimum breaking strength	38.40	35.20	17.60	14.60
Obtained:				
Mean breaking strength	47.83	45.17	22.36	21.28
Maximum breaking strength	49.85	45.73	24.25	22.08
Minimum breaking strength	45.90	44.60	21.16	20.47

STEEL STRAPS FROM 16 TO 30 MILLIMETRES IN THICKNESS (INCLUSIVE). MAKER, D.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	48.00	42.00	22.00	17.00
Minimum breaking strength	38.40	33.60	17.60	13.60
Obtained:				
Mean breaking strength	49.55	47.40	23.27	24.15
Maximum breaking strength	50.30	47.40	24.03	24.15
Minimum breaking strength	48.80	47.40	22.50	24.15

STEEL ANGLE IRONS FROM 3 TO 4 MILLIMETRES IN THICKNESS (EXCLUSIVE). MAKER, B.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	48.00	....	18.00	....
Minimum breaking strength	38.40	....	14.40	....
Breaking strength obtained	50.70	....	20.03	....

STEEL ANGLE IRONS FROM 4 TO 6 MILLIMETRES IN THICKNESS (EXCLUSIVE).

MAKER, B.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	48.00	....	20.00	....
Minimum breaking strength.....	38.40	....	16.00	....
Obtained:				
Mean breaking strength.........	48.85	....	21.20	....
Maximum breaking strength....	49.33	....	21.87	....
Minimum breaking strength.....	48.21	....	20.41	....

STEEL ANGLE IRONS FROM 6 TO 25 MILLIMETRES IN THICKNESS (INCLUSIVE).

MAKERS, A., B., C.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	48.00	....	22.00	....
Minimum breaking strength.....	38.40	....	17.60	....
Obtained:				
Mean breaking strength, A......	51.60	....	24.05	....
Mean breaking strength, B......	48.37	....	23.82	....
Mean breaking strength, C......	48.21	....	23.46	....
Maximum breaking strength, A..	52.90	....	24.20	....
Maximum breaking strength, B..	49.66	....	27.16	....
Maximum breaking strength, C..	50.30	....	25.81	....
Minimum breaking strength, A..	50.30	....	23.90	....
Minimum breaking strength, B..	45.69	....	20.41	....
Minimum breaking strength, C..	45.66	....	20.00	....

STEEL T-BARS FROM 4 TO 25 MILLIMETRES IN THICKNESS (INCLUSIVE). MAKERS, A., C.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength.........	48.00	....	20.00	....
Minimum breaking strength....	38.40	....	16.00	....
Obtained:				
Mean breaking strength, A......	50.06	....	23.64	....
Mean breaking strength, C......	49.65	....	22.25	....
Maximum breaking strength, A.	53.30	....	25.40	....
Maximum breaking strength, C.	52.00	....	23.50	....
Minimum breaking strength, A.	48.90	....	20.30	....
Minimum breaking strength, C.	47.30	....	21.00	....

STEEL CHANNEL BARS 6 TO 20 MILLIMETRES IN THICKNESS (INCLUSIVE). MAKER, E.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	46.00	....	18.00	....
Minimum breaking strength	36.80	....	14.40	....
Obtained:				
Mean breaking strength	47.78	....	22.00	....
Maximum breaking strength	49.55	....	22.50	....
Minimum breaking strength	46.00	....	21.50	....

STEEL DOUBLE T AND T BULB BARS FROM 6 TO 25 MILLIMETRES IN THICKNESS (INCLUSIVE). MAKERS, A., C., E.

SUMMARY OF RESULTS.

	Mean breaking load.		Mean elongation per cent. at rupture.	
	Lengthwise.	Crosswise.	Lengthwise.	Crosswise.
Required:				
Mean breaking strength	46.00	....	18.00	....
Minimum breaking strength	36.80	....	14.40	....
Obtained:				
Mean breaking strength, A	49.45	....	24.60	....
Mean breaking strength, C	48.48	....	22.11	....
Mean breaking strength, E	47.37	....	23.78	....
Maximum breaking strength, A	50.90	....	25.70	....
Maximum breaking strength, C	56.10	....	23.81	....
Maximum breaking strength, E	50.60	....	25.90	....
Minimum breaking strength, A	48.50	....	22.70	....
Minimum breaking strength, C	44.50	....	20.17	....
Minimum breaking strength, E	45.00	....	20.25	....

GENERAL OBSERVATION.

In conformity with the terms of the ministerial circulars of the 17th February, 1868, and of the 11th May, 1876, six tests at least must be made for each delivery. The figures in the tables are the means of the results of all the tests of each delivery.

As to the results *required*, the figures in the tables under the headings "mean" and "minimum" relate the first to the minima below which the mean results of all the tests of any one delivery must not fall; the second to the minima below which the results of an *isolated* test on any sound bar must not fall.

DISCUSSION.

DR. SIEMENS. The paper which has just been read before the Institution is one of very great interest to naval architects, because it brings before us the practice developing in a neighboring country, in which steel was used at a very early date indeed for naval construction. If I may be allowed to discuss the end of the paper first, I would refer to the remarks of the author upon the liability of steel to rust; and I would here draw attention to a very exhaustive discussion which took place only a week or more ago at the Institution of Civil Engineers. There an alarming account was presented, showing that steel rusted more rapidly than iron; but after two evenings' discussion the prevailing opinion arrived at was that with steel of a proper character this was not the case; and the facts brought before the Institution left no doubt upon the subject. Now, with regard to the French practice, I wish to mention that the open-hearth process used in the production of steel plates in France differs essentially from the process that has been more generally adopted in this country. There the Siemens-Martin process is used, and steel is made by the fusion of scrap steel or scrap iron with pig metal, and the final addition of spiegel, whereas in this country the process with which my name is more exclusively connected—whereby steel is produced by the use of ore and pig metal only—is practiced by most of the large works which carry on that manufacture; and I am disposed to consider that there is an essential difference between the two kinds of steel; for you get a more refined and homogeneous metal by employing only very little scrap and using the ore instead of the scrap process. This difference may account for the less favorable results which the French Navy appears to have obtained as regards the corrosion of their ships. I would attribute that result also in some measure to their continuing to use iron rivets in the construction of steel hulls. The discussion already referred to brought out the most variable results regarding corrosion. In one case steel seemed to corrode much more quickly than iron. In other cases, in experiments continued over years, steel showed decidedly less corrosion than iron. But one thing is certain, that when different materials are brought into contact with one another, and with sea-water, rapid corrosion of the one or the other will ensue, and I could not too strongly urge the desirability of using in naval construction one material only, be it iron or be it steel. As I have mentioned the process with which I am most intimately connected, I wish it to be understood that I have no desire whatever to set that process before any other. I do not think that users of steel should inquire too much into the process involved. We had yesterday brought before us facts regarding certain materials that had been used, which speak for themselves; and plates, different parts of which give different analyses, are evidently materials that ought never to have been employed. It is in the users' power to ascertain whether the material they propose to use, and which is supposed to be homogeneous, is so or not. I was reproached for not having gone into the causes of the failure of the material employed in the construction of the *Livadia's* boilers, but the facts speak for themselves. Metal that is brought into the ship-yard ought to be, above all things, homogeneous. I mentioned yesterday a circumstance which gave rise to great difference of opinion. I said that good mild steel should not lose strength in being punched, but should rather gain strength. My lord, I have since then looked up such experimental facts as I happened to have at my office in support of that view. I have here a report which was made by an assistant to Mr. Rendel, who wished to see what the effect of punching was, and those experiments were made in consequence of observations I made at the Institution of Civil Engineers. The result of the experiments, which are very accurate and perfect, is as follows: In a strip that broke with 30½ tons to the square inch, when one hole was punched the strength diminished to 30 tons per square inch; when two holes were punched side by side the strength increased per square inch to 31.65 tons; and when three holes were punched the strength was increased to 32.65 tons per square inch, showing an increase of more than two tons to the square inch after having been punched or disturbed in the greatest possible manner; and I hold that the most crucial, the most searching, test this homogeneous metal can be put to is to punch it with several holes at close distances in a line. If it is really high-class metal, it will simply flow when it is put to a great local strain, and the ultimate strength will increase, for the same reason that if a bar is stretched to a certain extent its strength per square inch is increased. But if it is metal that is not capable of perfectly solid flow it will diminish in strength. I have here, also, experiments by Professor Kennedy; these experiments will shortly be published by the Institution of Mechanical Engineers, and also go in support of the view I stated yesterday, that of good mild steel it might be said, what the old proverb attributes to "a wife and a mulberry tree," "the more you beat it, the better it be."

Mr. RILEY. I can quite confirm what has been said on the subject of corrosion, which is a very important one. I am very sorry that Mr. Denny is not here to speak on this matter. He is possessed of information bearing strongly upon this point which would, I think, tend to allay any anxiety about it. I am in possession of a number of letters from people who have used steel for boilers and in other ways, in all of which the writers, without exception, state that they see no difference with regard to the liability to corrosion of steel as compared with iron. I think Dr. Siemens has pointed out the cause of the different results the French Navy has found, and Mr. Martell also spoke yesterday in the same direction, and previously with regard to the use of iron rivets in steel plates.

Mr. SAMUDA. My lord, I have the advantage of personal acquaintance with M. Berrier Fontaine, and I know that the extreme care with which he examines everything in which he is interested may enable us to accept his paper as being most accurate in the details which he gives us. I am sure that there is nothing there but what he has most carefully analyzed and has been most particular to put forward in a way which we can rely on. I am sorry that in that paper he should have come to two or three conclusions—or, at any rate, that his directors in the navy should have come to conclusions—which do not appear to me to be necessary, and which, taken simply from the paper as given, might militate unfavorably against the advance of steel. I notice that one of the portions of his paper says that up to the present time they have not had a sufficient amount of confidence in the durability of steel to enable them to use it below water, and that all the below-water surface of the ship is of iron. Well, that I think is a very great pity. I believe there is a great deal in what has fallen from Dr. Siemens which would probably act in the opposite direction; and make it a positive objection to the durability of the remaining portion of the steel, that you should use two different metals exposed on the surface to the action of the sea and corrosion, and the electric influences that might thereby be generated. Then with regard to rivets, I see that he still adheres to iron rivets. Well, the difference between an extremely good bar of iron, such as the Lowmoor rivets, and steel, is so small as compared with that which exists in plates, that it might encourage people to go on longer with the use of iron rivets, and to disregard a close examination as to what the result would be. But now I can speak most positively with respect to the good effect of using steel rivets. Our own admiralty for a great many years followed exactly the same course as M. Berrier Fontaine. They rejected steel rivets and used iron; I mean with steel plates. I used steel rivets as long ago as 1868. Those vessels that they were used in have in one or two instances had to have the rivets removed, in one instance by reason of a collision that took place, and in another by reason of the vessel going onto a rock and requiring plates to be taken out and restored. The difficulty of getting these rivets out was something enormous, and instanced immensely the advantage of having them in, and I believe the sooner people get rid of the idea that inconvenience is likely to result from using steel rivets in preference to iron the better.

Mr. W. H. White. There being no one else here from the admiralty, I desire just to say two or three words about this paper, and the points raised by Dr. Siemens and M. Berrier Fontaine. First of all, it is an undoubted advantage for the French, especially in the arsenal of Toulon, to have started afresh. They created the plant with which they are working the steel almost absolutely, and that plant is almost entirely hydraulic—plant which does the work cold in a very admirable way. M. Berrier Fontaine read a paper before the Society of Mechanical Engineers, in which he described all the appliances that had been erected for doing the work cold, as far as possible, and this is a great advantage to them. But we have to do our work here in ship-yards which were constructed for working in iron; and, therefore, although we might have a similar advantage in new yards, it is difficult to realize now. The French, as those who visited the exhibition of 1878, very well know, have gone very much further than we have in the production of finished sections. Those double T's and other special sections of great length and size and expense which they use, no doubt help them in another way. In the framing of ships, for example, instead of bending hot, and putting together two angle bars by riveting in the way we do, they bend their frames cold and have these finished sections to begin with, thus avoiding certain operations which may affect the quality of the steel if carelessly conducted. I believe myself it is the true system. I believe the ship-builder ought to get from the manufacturer what he wants in the shape of finished sections as much as possible. Then, there is another thing, which is, the relative price of plates and angles. According to M. Berrier Fontaine, in France they can buy their steel as cheaply as they can their iron; so can we, such iron as we use for the admiralty ships. Mr. Barnaby has made that statement before. We can buy cheaper than we buy the special iron which we use to insure good quality; but I do not think that applies throughout the Mercantile Marine. I should be very glad if some gentleman can say in the course of the discussion what is about the relative price of iron such as is generally used for ship-building, and steel such as has been used hitherto under a system of tests to which I think there is no counterpart in the case of iron. Now, as to the corrosion. In the *Iris*, which has been in the Mediterranean for some months, there was evidence of corrosion. The facts are simply these: That although great and immense trouble was taken at Pembroke to get the manufacturer's scale off the surface of the plating, it did not succeed altogether. Some of this black oxide was left on; it set up a galvanic action in certain parts of the plate. That is the whole secret. There is nothing to be afraid of; there is nothing to be surprised at. We knew that this might happen, but we hoped we had got rid of this scale. Unfortunately for us we had not got rid of it. As to the riveting, I hope it is not imagined that we continue to use iron rivets in the Navy. We do not. As soon as we got rivet steel that we could trust we used it. The first attempts that were made in that direction were not altogether satisfactory. Dr. Siemens has spoken of the circumstances here (see Transactions for 1878). But we do now get a very mild quality of steel, which is worked with perfect success. The only thing is that the men have a little more labor in knocking down the rivets, and expect to be paid a little more; but we have this advantage, we can use smaller rivets, or fewer rivets, and therefore keep up the effective sectional areas of butted plates. In the *Iris* and the *Mercury* we did not want steel rivets; we could do without them. In some of our larger ships we do want them. By riming out the holes while countersinking, the full strength of the plate—28 instead of 26 tons per square inch of sectional area remaining—may be obtained, even when holes are punched; and it may then happen that the use of steel rivets will economize work. But iron rivets might also be used satisfactorily if desired, possibly with butt straps of special shapes, and certainly with a greater amount of work on the butt fastenings. I quite agree with Dr. Siemens, that now we can get a material for rivets of the same quality as the plates, or nearly so, it is the best thing possible to use steel rivets instead of the iron. One word about punching, my lord, and I shall have done. I noticed, as Dr. Siemens held that paper in his hand, that the experiments to which he referred were apparently made with very narrow strips. I myself have had to do with punching some scores of strips of steel of various widths, and my experience is, that the larger the hole punched in relation to the width of the strip, the better for the tensile strength of the remaining part of the section. If you punch a hole near the edge of an iron plate, the iron between the hole and the edge seems to suffer very much, whereas in the steel strips we have punched it really seemed as if the extreme ductility of the material made it gain. Dr. Siemens will find the results in Mr. Barnaby's paper, and in the Transactions of the Iron and Steel Institute.

Mr. West. My lord, I wish to say a few words upon the subject of corrosion. We have now a number of steel vessels classed with us, some of which have made voyages in very warm waters, on the coast of Africa. Those vessels after the first voyage showed what has been called "pitting" to a very considerable extent. It was quite enough to give us some concern. But on tracing it, it was found invariably to have occurred where there had been mechanical destruction of the paint, either from rubbing against wreck, or rubbing against a hulk, or something of that kind. After the second voyages of these vessels, after they had been coated again, the corrosion was less marked; after the third voyage it was still less marked; and now I would say it is practically the same as would be found in any iron ship. It will be in the minds of a good many Liverpool people that iron vessels from all parts of the country, some fourteen or fifteen years ago, showed a great amount of local corrosion in the rivets, so much so that in some instances the points of the rivets were $\frac{1}{8}$ or $\frac{3}{16}$ inch below the surface of the plate, and the vessels had to be reriveted. I mention this as a grave instance of corrosion in iron as well as steel. I am very glad to see in this paper a confirmation of my views in regard to the use of harder steel; the results of experiments made since I wrote on this subject have been such as to confirm us in its use. I believe that other people also are coming to the same view, and by and by we shall have a more general use for ship-building purposes of the harder class of steel. With reference to rivets I may say that we have invariably used steel rivets, and have found no objection to them at all, though I quite agree with Mr. Samuda that this excellent quality of iron is very much the same as the quality of steel that we are using for steel rivets. There was so much exception taken to what I said yesterday, that I should like to explain that the general tenor of my argument was this: That we must deal with steel in a practical way, and at present must be content with punched plates. I do not wish to say that the experiments to which I referred were conclusive; I only mentioned them as indicating that there was not such a very serious loss of strength as was sometimes stated. As we have no better practical method of treating steel plates for ship-building than punching them, do not let us be unnecessarily frightened to use the ordinary means we have.

The PRESIDENT. I understand nobody else has any further observation to make. Then it only remains for me to ask you to join with me in returning our very sincere thanks, and they are certainly due, to M. Berrier Fontaine for this most interesting paper. It may be perhaps well that I should tell the Institute who M. Berrier Fontaine is, because some of you may not know. He is nothing less than one of the most eminent French naval architects, and he holds in that country a position somewhat analogous to that which our chief constructors hold in this country, so much to the advantage of the country and so much to our advantage as an Institute. It is most desirable that our foreign competitors and friends should give us the results of their practical experience, and we ought to be most grateful for the time and trouble which M. Berrier Fontaine has expended upon this most elaborate paper. I must also ask you, gentlemen, to recognize the services done to this Institute by Mr. Merrifield. His services are so well known that it would be almost supererogation to mention them, but I may tell you, in regard to this particular instance, that Mr. Merrifield translated this paper, which is 80 pages long, closely written, in a single day. Now, that is a feat which certainly adds the reputation of being a very eminent French scholar to his well-known reputation as a first-class mathematician. One other explanation: Mr. Merrifield, very wisely I think, in consideration of our time, omitted certain details. I am sure I speak his own mind when I say that he did not mean to convey that those details were not well worthy of attention and study; but being details, he wisely chose the more prominent features of the paper to read to us to-day, merely on account of the saving of time. Those details are valuable, not only to the manufacturers of steel, but they are of essential value to the workmen employed in the manufacture of steel. I only wish I could think that our workmen in this country could have the opportunity of carefully studying this paper, because I am quite sure it would be of immense use to them. Everything that tends to increase the intelligence and the experience of our workmen in this country in such a delicate manufacture as that of steel must be of inestimable value. I am sure I may convey most cordially our gratitude to M. Berrier Fontaine for his most excellent paper.

THE ALMIRANTE BROWN ARGENTINE-CASED CORVETTE, AND THE EFFECT OF STEEL HULLS AND STEEL-FACED ARMOR ON FUTURE WAR-SHIPS.

By J. D'A. Samuda, M. I. N. A., *Vice-President.*

[Read at the twenty-second session of the Institution of Naval Architects, April 6, 1881, the Right Hon. the Earl of Ravensworth, president, in the chair.]

It is just twenty years since I read a paper to this Institution "On the construction of iron vessels of war iron-cased." Iron-clad building was then in its infancy. The first of these vessels, the *Thunderbolt* and her consorts, were the only iron vessels afloat clad with armor. The *Warrior* and *Black Prince* were under construction, as were also the smaller iron-clad frigates, *Defence* and *Resistance*, while the *Hector* and *Valiant* were only just about to be laid down.

Perhaps no amount of mechanical changes has ever been brought into practice equal to those which we have since then seen adopted in the building of iron-clads; mainly stimulated, no doubt, by an even more rapid development of the means of offense that has been arrayed against them, through the great improvement in the power of naval guns.

Our transactions and other works of interest may profitably be studied to obtain information on the many and vast improvements in iron-clads of all sorts that have since been constructed, and I do not propose to refer further to those engineering works and achievements of naval architecture which have marked the interval, but I propose in this paper to give an account of the last war-vessel I have constructed for the Argentine Government, the *Almirante Brown*, which in many points has a special interest, and marks a new departure that no doubt will result in vast and rapid development of our naval defenses.

The *Almirante Brown* is, I believe, the first vessel afloat which has been constructed entirely of steel and coated with steel-faced armor, and I believe a reference to her guns carried, the armor-resisting power obtained, and the great capability of steaming without recoaling, will show advantages beyond those possessed by any previous vessel of similar tonnage and power, results mainly due to the material employed in the construction of hull and armor.

General statement of dimensions, armament, engines, etc.

DIMENSIONS.

	Ft.	In.
Length between the perpendiculars	240	0
Breadth of beam, extreme, on water line	50	0
Depth from garboard strake to under side of main deck	23	11

Draught of water at load-line: aft, 20 feet 6 inches; forward, 19 feet 6 inches.

Mean	20	0
Height of port above L. W. line	7	6
	Tons.	
Displacement at load line	4,200	
Engines: indicated horse-power	4,500	
	Knots.	
Guaranteed speed per hour, in knots, with 900 tons dead weight on board.	$13\frac{3}{4}$	
	Number.	
Complement of men and officers	230	

Armament: six 8-inch $11\frac{1}{2}$ tons long breech-loading guns in central battery; two ditto on upper deck, and six $4\frac{3}{4}$-inch broadside guns.

	Ft.	In.
Height of armor above L. W. line, amidships	13	6
Height of armor forward and aft	3	0
Depth below L. W. line	4	0

	In.
Thickness of armor on belt amidships, steel-faced	9 & 6
Thickness of armor forward and aft	7, $6\frac{1}{2}$ & 5
Thickness of battery sides, steel-faced	8 & 6
Thickness of battery ends, steel-faced	7 & 6
Deck plating:	
Main and lower decks, steel	$1\frac{1}{2}$ & $1\frac{1}{4}$
Deck over battery, steel	$\frac{5}{8}$
Thickness of teak backing	11 & 8

STATEMENT OF WEIGHTS.

	Tons.
Hull of vessel	1,310
Armor plates and fastenings	690
Teak backing	85
Deck plating on main and lower decks and over battery	231
Masts, spars, rigging, blocks, and sails	30
Anchors and cables	50
Boats, galleys, condensers, &c	29
Wood and zinc sheathing	105
Engines, boilers, and spare gear	750
Armament, guns, ammunition, small arms, racers, pivots, &c.; coal; officers, men, and effects; water for four weeks; provisions, spirits, &c., for twelve weeks; officers' stores, slops, wood, sand, and holystone; warrant officers' stores	900
	4,180
Margin	20
	4,200

This is a vessel of moderate size, combining all the latest improvements in construction, armor, and armament. The hull is built entirely of Siemens steel; the armor is "compound" or steel-faced, consisting of an armor belt extending 120 feet in length, and protecting the engines, boilers, and magazines, with cross-armored bulkheads at ends of belt reaching from 4 feet below the water-line to the main deck. Above the main deck amidships is an armor-plated battery, with double embrasures at the fore end, and containing in all six guns. The armor-plates are worked on a teak backing, and are screwed to the skin with bolts and nuts from the inside, so arranged as not to wound the steel face of the armor. Horizontal armor of steel plates is worked from the battery to ends of vessel, forming a shell-proof and water-tight deck 4 feet below the water, protecting the steering apparatus, &c. The bottom is covered with teak planking 3 inches thick, and zinc sheathing from keel to 3 feet above water, as a protection against fouling. The vessel is fitted with double bottom, and divided by transverse bulkheads and steel decks into forty-eight water-tight compartments. The plating of the hull varies from $\frac{5}{8}$ to $\frac{7}{16}$ inches, except behind the armor, where it is 1 inch thick. She has two pole masts, and an area of sail of 10,000 square feet.

The armament consists of six Armstrong's improved type 8-inch 11½-ton long breech-loading guns fitted in battery, and so arranged as to give an all-round fire; one similar gun on upper deck forward and one aft; also six 4½ inches broadside guns on upper deck.

The engines consist of two sets of inverted compound surface condensing engines of the collective indicated power of 4,500 horses—each set working its own screw, and being fitted in its own separate engine-room. The boilers are eight in number, cylindrical; the boiler-room being divided into four separate water-tight compartments.

The steel-faced armor used, of 9-inch thickness, has been found in practice to be equal in shot resistance to iron armor of 12 inches thick, and to resist a shot from a 12-ton muzzle-loading gun at 10 yards; while the guns used in this vessel, though weighing each only 11½ tons, are able to penetrate 13.3 inches of ordinary armor at 70 yards, and this is equal to the penetrating power of the service muzzle-loaders of 18 tons weight.

A reference to the drawing exhibited shows that no less than five of the guns can be brought to act almost in a direct line ahead; while an all-round fire is obtainable in which nearly every gun can participate.

The speed is expected to reach 13¾ knots, and the coal carried is sufficient to enable the vessel to steam at a low rate of speed—say 8 knots, 6,000 miles, or at a speed of 10 knots to cover 4,300 miles of distance.

The effect of substituting steel for iron in the hull, and steel-faced armor for iron armor, has been to obtain the same strength and resistance to shot that could have only been obtained in an iron vessel of similar size and strength with 510 tons additional material, and when increased in dimensions to meet this (as given below) a further 350 tons would be needed for the extra weight due to the enlarged hull.

An iron built and armored vessel constructed to carry this additional weight, and of such extra dimensions as would be necessary if the same speed were to be maintained, draught of water preserved, and coal-carrying capacity maintained, would have to be increased in size, displacement, and power as follows:

The iron ship would have to be constructed—

Length	feet	260
Breadth	do	55
Displacement	tons	5,200
Coal to be carried	do	720
Power	do	5,000

Against the steel vessel with steel-faced armor, as already described and being, viz:

Length	feet	240
Breadth	do	50
Displacement	tons	4,200
Coal to be carried	do	650
Power	do	4,500

In other words, it would involve 1,000 tons additional displacement, and 500 additional horse-power, to possess equal speed and shot-resisting power and to carry 70 tons additional coal to enable it to travel an equal mileage without recoaling.

The increase of the material is arrived at from adopting one-quarter extra thickness in iron in the hull beyond that used for steel, which barely gives an equivalent strength, and one-third more weight in the armor than that used in the steel-faced armor which gives the iron armor the same resisting power as the steel-faced, and the 1,000 tons extra displacement needed is the unavoidable result of carrying this increased weight of hull, armor, engines, and coal, with equally good lines on a similar draught of water, and with the increased power needed for driving the larger ship at the same rate and over the same distance as the present vessel provides for.

I know that some doubts have been expressed as to the equal reliability of steel structures to those of iron; but I must here say that my experience (and it has now reached over many years) does not agree in sustaining any such doubt. I have found steel, especially the Siemens-Martin steel used here, in all respects a superior material to iron. It possesses one-third more tensile strength, is much more ductile both hot and cold; can be efficiently worked cold in most cases when iron must be worked hot, and where properly prepared and annealed where necessary, and properly coated with paint, has in no instance given any symptoms of unreliability or of premature decay.

I do not wish to assume to myself any undue credit for advancing the use of steel in place of iron. I know that the profession is greatly indebted to many others, and especially to the present director of naval construction of the Navy, Mr. Barnaby and his staff, for advancing the practical application of steel in the very highest degree, and that the very fast cruisers *Iris* and *Mercury* and the six sloops of the *Comus* class are most important and successful instances of the usefulness of steel, while they have not been behind in applying it to armored vessels; and, though not yet afloat, the *Conqueror*, the *Colossus*, the *Majestic*, and the *Polyphemus*, are being built not only of steel but with the intention of using compound or steel-faced armor, as in the *Almirante Brown;* and I regard with no small satisfaction the confidence shown by such authorities, and the effect it must have in shortening the time necessary to produce a general if not a universal appreciation of the advantages to be looked for from the use of steel instead of iron in structures of all descriptions.

I am unable in the present paper to do more than state generally the expected speed we shall obtain.* As yet the vessel, though on the point of completion, has not made her steam trials, and with the permission of the Institution I will add to this, when they have been completed, a note giving the results.

I was anxious, however, not to keep back this paper for any such information, believing as I do that steel in the construction of armor-clad vessels is about to become so important a factor that attention cannot be called to it too early, and I trust that by stimulating the consideration of the subject and affording the opportunity for discussing its important advantages, this paper may not be without some slight benefit.

DISCUSSION.

Sir JOHN HAY. My lord and gentlemen, I should like first of all to thank Mr. Samuda for the very interesting paper which he has just given us, pointing out that which I am sure we want very much, the best description of small iron-clad vessel for the service of the Navy. I see the comptroller of the navy here, and I would recommend, I do not say this particular form of vessel, but a vessel very much of this kind for his consideration. A most interesting paper read before the United Service Institution by Captain Colomb points out that for the service of the state it is necessary that we should have at least sixty-two iron-clads. I believe that has been admitted by a great many persons as being the smallest number with which the protection of this country and her ocean carrying trade can be carried on. Captain Colomb received the gold medal of the Institution for his paper, and I have never seen his calculations at all taken exception to or contradicted. Suppose that sixty-two ironclads are necessary for the service of the state, I have recently heard in the House of Commons, on the authority of the secretary of the admiralty, that they have twenty-one fewer than is absolutely required for the service of the state, and it would be impossible, in my opinion, to complete in a short time twenty-one iron-clads of the required dimensions, which some people think are necessary for our men-of-war. It is quite true that the Italian navy has four vessels, or

* The official trial of the *Almirante Brown* on the Maplin Mile on the 14th June, 1881, gave a mean speed, taken over six runs (three with and three against the tide) of 14.042 knots. Draught of water 19 feet 2 inches; mean displacement, 4,237 tons.

will soon have, of a size greater than any ships we have except the *Inflexible.* It may be necessary to complete a certain number of ships of great size to compete with those vessels, but for the ordinary service of the state it seems to me that it might be well to proceed with the construction of and complete the twenty-one smaller iron-clads which are necessary for the protection of our carrying trade in the event of war. I venture to say that complete impenetrability or invulnerability of a ship is an entirely novel idea. When some twenty years ago the question of iron-clads was first considered, shell-firing on wooden ships was recognized as a great danger—that it would set fire to the ships—and it was considered necessary to put on iron enough to prevent shells penetrating and setting fire to them, but the condition of entire invulnerability was never for a moment imagined. But if you build your ships of steel instead of wood you get rid of the splintering of the old construction, and also the danger of the ship being set on fire. Those two dangers being got rid of, it seems to me that if you protect your men at the guns, in the magazine, and engine-room thoroughly, you may get rid of the entire protection of the whole ship by impenetrable armor. Then you come to the possibility of having a ship of a tolerably small size with iron protection in a certain degree. such as the one which has been just described to us by Mr. Samuda. Now, with reference to the vessel itself, in the first place, and with regard to the position of the guns, I would venture to offer a criticism. It seems to me that persons engaged in working or firing the bow or stern gun would be in considerable danger, or at any rate in considerable discomfort or nervous apprehension, not from the enemy, but from the persons firing those two guns in a right line. I believe it would be difficult to get a bow or stern fire from those three guns at once. Nor do I think 13½ knots is quite sufficient speed. I would be glad to sacrifice something of protection in order to gain greater speed. I have the greatest belief in great speed. I believe that speed is, after all, almost the greatest element, next to sufficient coal-carrying power, with these vessels here described, especially the larger design of the two. There is another great advantage in these vessels which the larger vessels have not. Many of the operations of the navy are conducted in places (in our days especially) where a light draught is of the greatest possible advantage. We well remember that a neighboring nation failed to perform some of the operations which it was thought were necessary by reason of the great draught of her iron-clad ships. Not only that, but there are rivers which I need not mention where the operations of an iron-clad might be necessary, and where iron-clads might be useful; and the draught of our ships with regard to the Suez Canal should be attended to. No vessel of more than 24 feet draught can go through, and a vessel that can go to the Mediterranean and cannot proceed to the Red Sea is not so useful as a vessel that can be used in both oceans.

Sir Spencer Robinson. I do not propose to follow Sir John Hay, because I think the criticism which he has passed, in a great measure, or the observations that he has made on the subject of iron-clad ships, would be more fitly addressed to the members of the government in the House of Commons than to an institution of naval architects. There are no doubt many general points of importance that Sir John Hay has touched upon in detail which also have been alluded to by your lordship. It is with regard to those general principles that I wish to offer a few remarks, inasmuch as ever since I had the honor of belonging to this Institution I have been a very great advocate of the use of steel for ship-building; and I have lived long enough to congratulate this Institution on the great success that has followed all its efforts, and they have been unceasing and unbounded, and there are many gentlemen listening to me who have undergone a great many disappointments, and who have incurred a great deal of expenditure, to bring forward the use of steel in the construction of our ships, both our merchant ships and our ships of war. I would congratulate the Institution on seeing, as far as it has seen, the successful result of its labors, and all those who have advocated in this hall the construction of steel must feel pleased that so many of the difficulties have been overcome, and if not absolutely banished forever from their calculations, still great success has attended the experiments, and I think there is every prospect in the future for steel, with all its advantages, many of which have been illustrated by Mr. Samuda in the ship which he has designed. I have been also all my life an advocate, as Sir John Hay expresses himself, an advocate for speed. The speed of our ships is a most important matter, but next to that, if not even beyond it, at any rate *pari passu* with it, must go the coal-carrying capacity of our ships. The coal-carrying capacity of our ships is the one thing of all others which requires the most attention, which will produce the most important results, and without it is largely increased—and I say so advisedly—the utility that people hope to derive from protecting our commerce by iron-clad or any other ships will be frustrated. It is in the coal-carrying power of our ships of war of high speed that the protection of our commerce will find its greatest and most powerful shield. If we are satisfied, as I hope we shall not be, with small stowage of coal and low speed, we shall meet on the ocean people ready to destroy our commerce with ships of great speed and large coal-carrying capacity. All of you know—you know it even better than I—that when you say you will get large coal-carrying capacity and ships of great speed, there will be much difficulty in getting that ship of the small dimensions so much sought for, and it is absolutely necessary for the safety of your commerce on the seas that you should be prepared to sacrifice something large, not something small, for the coal-carrying capacity of your ships. Whether that shall be by surrendering a certain portion of armor or by surrendering what some of you love very dearly—the gallant admiral especially—the small size of our ships, it is not for me to say. I know this, that any problem of that kind I may put to naval architects worthy of the name—and the room is full of them—can be, and will be, successfully answered, and if you do not find a ship with large coal-carrying capacity and great speed, a ship of war, the fault lies with those who do not suggest and say to the naval architects whom they consult, that is the ship we want, and the only ship we will be satisfied with.

Mr. NATHANIEL BARNABY. My lord and gentlemen, I had not intended to rise and speak upon this paper, although it is one which I have heard and regarded with great interest, but as your lordship has been good enough to call upon me to speak I feel obliged to call attention to one point here where I think Mr. Samuda has somewhat overrated the value of steel-faced armor. I am sorry to have had myself to make the correction, and perhaps he may have some information which I have not which he may be able to set against what I am going to say, but the allowance which we make for the increased resisting power of steel-faced armor over iron is not one-third, as Mr. Samuda has given it, but I am afraid that we cannot say at this moment more than one-fourth. One-fourth is what we take for it. The time is probably coming when that new material will give a very much better result than that, but it is only fair, as I have to speak, that I should say what the fact is; and we have had more opportunity at the admiralty of seeing the results of the experiments on steel-faced armor and iron than other people have had. As it stands at present I should say that instead of taking one-third it would have been fair to have taken not more than one-fourth.

Sir E. J. REED, C. B., F. R. S., M. P. I, like Mr. Barnaby, had not intended to say anything on this paper, but you have been pleased to ask me to do so, and I will just say a word or two. I do not admire this design quite so much as my friend Mr. Samuda does, and for a reason which I will mention. I do not believe myself, although I have been all my life, almost, an advocate of short iron-clads in the navy, in making a ship with the limited protection which that ship has as regards the extent of her length, as short and blunt and hard to drive as she is. Of course, if you are going to make a real iron-clad ship, and the skin of the ship is to be protected from stem to stern for any considerable depth by thick and therefore heavy armor, then you cannot afford to make that a long ship in proportion; but if you are going to do away with armor on the bow and stern altogether, for so large a proportion of the length of the vessel as we have it dispensed with there, it seems to me that the justification for making a ship short and blunt and hard to drive disappears; and although I have built ships myself, as Mr. Samuda knows, of almost the same dimensions, I do not like this as well as my own, for the reason that I say that if I had been going to abandon armor on the bow and stern to the very large extent to which it is abandoned here, I should not have felt myself justified in making a ship of such blunt lines as that vessel must of necessity have. I do not see any reason why a battery and an engine and their related parts of that shape and size and character should not be associated with finer lines both forward and aft, if you intend to abandon armor upon it. I am quite aware, my lord, that in the introduction of a steel deck below the water a few feet down, that you have there an element of very considerable weight and value; but I do not observe that this ship resembles the admiralty vessels in that respect. So far as I can judge I believe I am right in saying from this paper that the armor plating of this under-water deck, 4 feet down, is only 1½ inches thick. Now, I do not see that an iron deck 1½ inches thick, exposed to the direct fire of depressed guns, can be regarded as an effectual protection for the lower part of the vessel against shot and shell. In the case of the admiralty ships, I think I am right in saying—although I can speak with no confidence, because the admiralty do not enlighten us very fully on some of these details of their ships nowadays—that usually the admiralty put an under-water deck of iron or steel 3 inches thick. I think that is a very substantial and effectual protection against depressed fire, but I cannot myself say that I think 1½ inches is. Then, if so, it would seem to follow at once that the proportions of the ship should be different. Mr. Samuda will understand that I am speaking here, not from any desire to criticise this particular vessel, which I admire in a very large degree; but the object in these discussions, I apprehend, is to confer together upon professional points, and to make our suggestions for the benefit of each other. What I wish to say is, that if you have a 3-inch armor deck to deal with, you have a very considerable weight in that, and a weight which will go far, when the ship is broad, towards making armor for the sides and continuing the belt in lieu of making the deck; and therefore you cannot afford with a thick armor deck, any more than with the iron belt continued, to make the ship long and fine, as you could otherwise do. But when you limit the thickness of the decks to 1½-inch iron, then, in my humble opinion, you can afford to give the ship the advantage of much finer lines, and therefore of greater speed for the power employed.

This ship, my lord, opens up a question which a great many of the admiralty ships have opened up, and which I feel a peculiar interest in, because in some respects, and perhaps in a very large degree, I am responsible for it. I considered when in the admiralty how best to have the principle adopted of an armored tower, or armored central part of the ship—call it citadel if you please—and an armored under-water deck without a belt on the ends of the ship. It seems to me that that, judiciously carried out, would enable you to carry, as is to be carried in the case of the *Inflexible* and more recent ships, a heavy-plated armor citadel in conjunction with good speed. But the difficulty I have is, to quite understand how ships treated as this ship is, and as a good many others are, are going to remain fast ships after they are attacked by other vessels. Now, any one looking at that plan can see at once that it does not require high skill, great determination, any great naval resource, or effort, to knock the bow of that ship about a bit, because a gunner can hardly fire at the ship at all within reasonable range without, either by accident or design, making a good many holes in the bow; and then the question arises, and it is one for this Institution really seriously to consider, whether it is possible to drive that ship after the bow has been seriously knocked about. I confess, for my own part, I am unable to see how it is possible to drive it. But, as your lordship is well aware, that question was considered by the *Inflexible* committee; and although the *Inflexible* committee wrote a good many pages in justification of the *Inflexible*, they wrote some (their consciences becoming active towards the end of the report) which were very important indeed. I cannot undertake to quote the report accurately, because I did not consider it a cheerful or pleasant document to dwell upon myself, but I do remember that in the report a statement is made of the most remarkable character. The *Inflexible* committee described, I believe, that I did not mispresent it—or at any rate, if they do not say it in words they do in substance—that very critical conditions would arise in a ship of this description. I must guard myself on the point, because Mr. Samuda has not, I see, given anything like so large a proportionate length of unprotected ship as existed in the *Inflexible;* but they stated this, that if one shot or shell entered the bow, and penetrated all the bulkheads as far aft as the armored bulkhead, then the ship's steaming power would be gone, and she could not be driven, except at a very low speed indeed, without the risk of the ship going down head first.

Mr. N. Barnaby. No.

Sir E. J. Reed. I understand Mr. Barnaby to say no, but at any rate the statement was that she would be in a very critical condition, and could not be driven at any but a slow speed. Now, I admit that that statement may have been accompanied by some extraordinary expressions of opinion to the effect that it was in the highest degree unlikely that any shot or shell would enter the unarmored bow, and go aft to the armored bulkhead; the difficulty which the *Inflexible* committee felt is one which I was not only unable to sympathize with, but which I was quite unable to understand. Is it not to be expected within the bounds of probability that a shot will do that? It seems to me that when one of these ships has the boldness to chase another, the first thing you are entitled to expect is that a shot will come in at the bow, and will go through all the unarmored bulkheads until it reaches the armored parts. In conclusion, I may be allowed to say that I think Mr. Samuda deserves immense credit for bringing before us a design which, as he says, is an example of the first case in which a steel ship has been associated with steel-faced armor.

Mr. J. D'Aguilar Samuda. My lord, I will now reply to some of the observations which have been made. In the first place, I will personally thank those gentlemen who have made them very much. I would observe first, in reference to the speed as spoken to by Sir John Hay, that we do expect we shall obtain 14 knots with this vessel; and although I quite agree that speed cannot be too highly estimated, it is the utmost we could get with the conditions on which this vessel has been built, having regard to its size and draught of water, and to the armor and coal which it was necessary to carry. One of those several points must have been sacrificed if we had decided on going at a higher speed, but we thought that 14 knots was a very high speed for armor-clad vessels at all, and vessels of this sort especially; and taking all those matters into consideration, it was probably better to accept the balance of advantage which we have by having a great deal of armor, a great deal of coal-carrying power, and perhaps a little less speed than would be desirable in the view of Sir John Hay. I hope and believe that this vessel does give effect to the observations of Sir Spencer Robinson, and that he will consider the coal-carrying capacity here as sufficient for the size of the vessel, and for what might be expected of her, as a general cruising useful vessel. This vessel, as I have endeavored to point out, is able to maintain her course for 4,000 miles at sea at 10 knots an hour without replenishing her coal, and that is as much as we could possibly do.

Sir Spencer Robinson. That is a very good result.

Mr. Samuda. With regard to Mr. Barnaby's observation, no doubt he is right; and if I had had the opportunity of having the benefit of his information and experience about the proportions of the resisting power of steel-faced armor, as compared with the ordinary armor, I would have inserted it in my paper, which takes it as one-third instead of one-fourth stronger. I based my conclusions on information from the makers of this plate of the general result that all the firing experience showed, and they sent me up all the photographs of the firing that had taken place. Now, Sir Edward Reed has made some observations which every one here must feel interested in. First, with regard to the vessel not being armored to the extreme ends, I gather from Sir Edward's observations that he would have preferred it to have been so constructed, in preference to having the horizontal armor, where that horizontal armor is only 1½ inches thick. That, of course, would be a question which might be decided either way, according to the wishes of those for whom the vessel is being constructed. But I will point out this, that if it were deemed desirable to accept that view, there would be no difficulty in accomplishing it, because the effect of carrying the side armor to the extreme ends of the ship, in substitution for the horizontal armor which is in that ship, would be to enable you to carry 6 inches of armor for the entire length fore and aft. With regard to the destruction that would take place at the bows from a single shot passing in where this horizontal armor is placed, that would apply to all vessels of this character being built at this time. The *Inflexible*, the *Agamemnon*, and the

Ajax, are all liable to the same observation; but I do not quite indorse the view that the same mischief would arise from penetration in the bow, as Sir Edward Reed suggests. I think if the bow is made—although that is the great difficulty with vessels of this sort—sufficiently strong to enable it to act as a ram, you overcome a great part of the difficulty. When you come to the use of steel, the difficulty with regard to its being damaged by penetration would be only to impede the general action of the ship in a very small degree, much less than, I think. the general breaking up contemplated by the observations which Sir Edward Reed puts forward.

Sir E. J. REED. Several holes.

Mr. SAMUDA. There are a large number of subdivisions in this vessel, and two of them being penetrated would not materially affect the general character of the ship.

The PRESIDENT. Gentlemen, I doubt not you will permit me on your behalf to offer to Mr. Samuda your thanks for his able and most interesting paper. There is one great moral, I think, to be derived from the type of ship he has brought before us, and if he deserves no other thanks he deserves thanks for this, and I trust that the admiralty will take it to heart, that he has shown us a remedy against putting too many eggs into one basket, and has suggested the construction of smaller and handier iron-clads which will be of very great advantage in many respects. When I saw the vessel, and the large opening necessary for training the guns so that one gun shall support another, it appeared to me to render the vessel liable to this danger, that a shell might very easily penetrate those very large openings, and that, combined with the fact which has been pointed out of the steel deck being only 1½ inches thick, would render it, I think, a very great danger to the vessel in action. I am sure you will allow me to convey to Mr. Samuda your thanks for his most able paper.

THE STRUCTURAL ARRANGEMENTS AND PROPORTIONS OF H. M. S. IRIS.

By William H. White, Esq., *Assistant Constructor of the Navy, Member of Council.*

[Read at the twentieth session of the Institution of Naval Architects, April 4, 1879; the Right Hon. Lord Hampton, G. C. B., D. C. L., president, in the chair.]

The use of mild steel as a substitute for iron in ship-building is now attracting so much attention that some interest will probably be felt in the brief description of the structural arrangements of H. M. S. *Iris*, which is given in this paper. It is well known that this vessel was the first built in England in which mild steel was employed; and that she was the first vessel of the Royal Navy wholly built of steel. Notwithstanding her exceptional character, as compared with other types of war ships or with merchant ships, it may be well to put on record in the Transactions, the facts as to her scantling and structural strength; for while she differs from most seagoing ships in many particulars, she illustrates, I think, some principles of construction that are applicable to all steel-built vessels.

It is necessary at the outset to sketch the general features of the design. The principal dimensions are as follows: Length between perpendiculars, 300 feet; breadth, extreme, 46 feet; depth, from upper deck, at side amidships, to under side of bar keel, 28 feet 4½ inches; depth of keel, 1 foot; mean load draught, 19 feet 9 inches; corresponding displacement, 3,735 tons.

Mr. Wright has given in his paper a full account of the propelling machinery, and the remarkable steam trials of the ship. I need not repeat the description here.

Fig. 1, Plate IX, shows in outline the manner in which the hold-space is occupied and subdivided. No less than 138 feet of the length is occupied by engines, boilers, and coals; there are two separate stokeholds and two engine-rooms. The engines and boilers are kept below the water-line, and protected throughout by wing coal-bunkers, varying in thickness from 5 feet to 8 feet between the upper and lower decks, and decreasing in thickness as the depth below water increases. These bunkers are more clearly shown in the "midship section" (Fig. 3, Plate X). The outline "profile view" (Fig. 2, Plate IX), shows the heights of the decks and platforms, the positions of the bulkheads, &c. Reference to these drawings will show that there are *ten* complete water-tight transverse bulkheads; and that in wake of the stokeholds, where the main bulkheads are 44 feet apart, intermediate or "partial" bulkheads are introduced in the coal-bunkers. The longitudinal bunker bulkheads are also water-tight; and throughout the length occupied by the machinery and boilers there is a water-tight inner skin, forming a complete double bottom (see Fig. 3, Plate X) across the ship between the bunkers. Before and abaft the double bottom, a water-tight platform is built about 7 feet below the lower deck, and extended to the bow and stern respectively This platform does not extend quite to the foremost boiler-room bulkhead, because the small "fore-hold" (about 14 feet in length) is nearly occupied with water-tanks and chain-lockers. In the coal-bunkers also there is a platform about mid-height between lower deck and bilge (see Fig. 2, Plate IX). As is usual in Her Majesty's service, the magazines and other inclosed spaces are formed into water-tight compartments; and altogether, there are no less than sixty-one separate compartments; twenty-one in the hold proper, and forty in the double bottom and bunkers. The various partition bulkheads just mentioned of course contribute largely to the structural strength, especially to the transverse strength; and this must be kept in view when examining the framing. In some respects the system of framing adopted in the *Iris* resembles that commonly used, in iron vessels of the Royal Navy, but in other respects it is novel. It may be said that the arrangement of the framing has been governed by the desire to efficiently stiffen and support the comparatively thin skin-plating, while avoiding the use of closely-spaced transverse frames. The skin-plating is $\frac{1}{2}$ inch thick, with a doubled sheer-strake; the garboard strakes are $\frac{5}{8}$ inch. Throughout the length of the double bottom the transverse frames are spaced 4 feet apart; before and abaft the double bottom the spacing is $3\frac{1}{2}$ feet. By means of the longitudinal framing, shown on Figs. 2 and 4, the unsupported spaces of the bottom-plating are kept down to 16 or 20 square feet, and buckling or unfairness is prevented.

The midship section (Fig. 3, Plate X) represents the system of framing in wake of the double bottom. The outer or frame angles are 6 by 3 by $\frac{7}{16}$; they are made continuous from the first longitudinal on one side to that on the other, passing through scores cut in the center or vertical keel-plate, and are again continuous from the upper deck down to the second longitudinal. Up to the turn of the bilge the transverse frames below the inner skin are on the well-known "bracket-plate" system, the brackets being formed of $\frac{5}{16}$-inch plates, and the short angles on their inner edges being 6 by 3 by $\frac{3}{8}$ between the keel and second longitudinal, but only 3 by 3 by $\frac{7}{16}$ between the second and third longitudinal, where a lightened plate is substituted for a bracket. Within the coal-bunkers the reversed frames are 3 by 3 by $\frac{7}{16}$. The center-plate keel is $\frac{3}{8}$ inch thick, with lightening holes in the spaces between the frames: its lower edge is riveted to the bar keel (iron). The longitudinals in the double bottom are formed of $\frac{5}{16}$-inch plates, with 3 by 3 by $\frac{3}{8}$ bars on the outer edges and $2\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{5}{16}$ bars on the inner edges, as shown in Fig. 5, Plate XI. Plates and bars are worked continuously, with butts carefully shifted and strapped, in the same way as is usually done in armored ships. The first longitudinal out from the keel on each side is made water-tight throughout the double bottom. In wake of the bunkers the light transverse framing is well stiffened by the lower deck stringer, and by the platform below the lower deck; besides which there are longitudinals formed of 10 by $3\frac{1}{2}$ by $3\frac{1}{2}$ by $\frac{7}{16}$ Z-bars (similar to those now used for frames behind armor in ironclads). These Z-bars are scored in over the 6-inch frames and secured to the skin-plating; a continuous 3 by 3 by $\frac{3}{8}$ angle-bar being worked inside the reversed frames and riveted to them and to the Z-bars. A strong and simple stiffener is thus secured with very little workmanship.

Outside the limits of the double bottom the framing is of the character shown in Fig. 4, Plate X. It closely resembles that described for the coal-bunker spaces, with the addition of a floor-plate, and a gutter-plate at the middle line. Care is taken to scarph-on the Z-bar longitudinals before and abaft the double bottom to the deep longitudinals within the double bottom. Fig. 6, Plate XI, shows an outline of the arrangement. The plates of the longitudinals are gradually reduced in depth, and a strake of the inner bottom is extended over the tapered portion of the longitudinal to strengthen the connection.

The inner bottom-plating is $\frac{5}{16}$ inch and $\frac{1}{4}$ inch in thickness; the edge-joints are single riveted, and butts double riveted. It is worked flush, as is usual in ships of the navy. Its vertical continuations, forming the coal bunker bulkheads, are of $\frac{1}{4}$-inch plating with 3 by 3 by $\frac{3}{8}$ vertical stiffeners placed 30 inches apart. This plating is lapped and single riveted at the edges, the butts being double riveted. The coal-bunker bulkheads are continuous, the transverse bulkheads being cut off where the two systems cross one another. This is a departure from common practice, but has obvious advantages. For nearly one-half of the length of the ship, where all the principal strains have to be resisted, and where the largest hatchways have to be cut in the decks, the ship's sides are constructed strictly on the cellular system, the inner and outer skins being stiffened independently as well as strongly connected to each other by the horizontal plating on deck and platforms, and by the vertical transverse bulkheads. The desire to provide coal protection for the engines and boilers was the primary cause of this arrangement, but it might probably be imitated with advantage in other classes of ships.

The outer bottom plating up to some distance above the bilge is worked in the usual manner with double chain-riveted lap joints. Above this height the plates are flush jointed at the edges, with continuous single-riveted internal strips; this is purely for the sake of appearance. The butts are all secured by double chain-riveted straps. It may be proper to state here that Staffordshire iron rivets are used throughout the ship, the sizes being the same as would be used with iron plates of the same thickness, but the pitch being reduced slightly in the butt fastenings to secure sufficient shearing strength. This was preferred either to using larger iron rivets, and consequently having heavier straps and laps, or to using steel rivets.

Respecting the transverse and other bulkheads in the hold, it will suffice to say that the usual practice is followed in construction; the plating is $\frac{1}{4}$ and $\frac{5}{16}$ inch thick, with vertical stiffeners 3 by 3 by $\frac{3}{8}$ placed 30 inches apart. Single-riveted lap joints are used in this work.

Considerations of durability are really paramount in the determination of the minimum thickness of plating that can be used in most of these partitions, and the gain by substituting steel for iron is comparatively unimportant.

There is nothing in the deck-framing which needs to be described, but it may be interesting to summarize the arrangements of the deck plating:

Upper deck.—A partial steel deck ($\frac{3}{8}$ inch) on each side, about 8 feet wide amidships, forming a top to the coal-bunker; before and abaft the bunkers this plating is gradually tapered to a stringer about 4 feet broad.

Lower deck.—A stringer plate, 30 inches wide and $\frac{3}{8}$ inch thick.

Platforms.—Before and abaft double bottom (water-tight), $\frac{1}{4}$-inch plating; in coal-bunker, $\frac{5}{16}$-inch plating.

The butts of all the longitudinal tie-plating are carefully strapped, and double chain riveted.

The framing of the extremities calls for very few remarks. A bar-stem (iron) is used, and the bow-framing is of the ordinary character. At the stern the only unusual features are consequent upon the extreme fineness of form. In order to decrease the labor of building, and the volume of internal spaces requiring to be filled in with cement, the bar-keel is ended about 30 feet before the sternpost. The true keel from that point is really a flat plate turned upwards, and carried along about 6 feet above the height of the under side of bar-keel produced. The space between the flat keel and the base line is made good by means of an external centerplate, having double angle irons on the upper and lower edges, and wood chocks bolted to the sides, with frequent bracket stiffeners in steel. Fig. 7, Plate XI, illustrates these details.

In the *Iris*, owing to her great power and fine form, the length of external shaft tubes is about 50 feet. Each tube is supported by two struts or A-frames, and the attachment of these to the hull has been satisfactorily arranged with only trifling additions to the framing proper. Fig. 7 illustrates this feature. Under the very severe and repeated tests consequent upon the long series of steam trials there has not been the least indication of weakness or want of rigidity at the after part, or indeed at any part of the ship. Another illustration of the possibility of meeting great local strains by comparatively small but judiciously applied additions to the ordinary framing is supplied by the engine-bearers of the *Iris*. Fig. 8 shows their general arrangement, and any detailed description is unnecessary.

It is now about two years since the *Iris* was launced at Pembroke. She has not yet been tried at sea, except on the short passage from Pembroke to Portsmouth, but in trials under way, repeated dockings, and under various conditions to which a ship is subjected while incomplete in a dock-yard, she has shown herself perfectly successful in resisting local strains. As to her capacity for resisting the principal strains to which a ship at sea is subjected, there can be no question. Her transverse strength is, as has been shown, exceptionally great. As to her longitudinal strength the following facts may be stated. When floating in still water she is subjected to hogging moments throughout her length. Fig. 20, Plate IX, shows the curves of weight, buoyancy, loads, shearing forces, and bending moments constructed in the usual manner. The maximum hogging moment in still water is 19,000 foot tons, or about equal to one-fifty-eighth of the product of the displacement by the length. To this bending moment there corresponds a maximum tensile strain on the upper deck of 2½ tons per square inch. Further, if the *Iris* is supposed to be balanced instantaneously on the crest of a wave of her own length (300 feet) and 15 feet high, her conditions of strain become modified, as shown in Fig. 20. The maximum hogging moment is then 38,000 foot tons (one-twenty-ninth of the product of displacement into length). To this bending moment there corresponds a maximum tensile strain on the upper deck of about 5 tons per square inch, or less than one-fifth of the ultimate strength of the material. This is an eminently satisfactory result. The neutral axis for hogging is about fifty-two one hundredths of the depth of the ship amidships below the upper deck at the side, so that the compressive strains on the bottom do not exceed a maximum of 4.6 tons per square inch. It is interesting to notice in passing that the maximum hogging moments of the *Iris* in still water and on the wave crest bear to one another a ratio differing from that of the corresponding moments for any ship subjected to hogging strains only in still water, of which the curves of weight, buoyancy, &c., have yet been published. Comparing her with the *Minotaur*, for example:

	Maximum hogging moment.
In still water:	
Minotaur	Displacement × length — 88
Iris	" " — 58
On wave crest:	
Minotaur	" " — 28
Iris	" " — 29

It is not necessary to discuss the differences in the distribution of weight and buoyancy, and in the forms of the ships which produce these results, as the corresponding curves for the *Minotaur* are before the public.

The *Iris* is now practically complete, and her weight of hull has been ascertained. It amounts to about 38½ per cent. of the load displacement, all the fittings being included. On investigation it is found that the saving effected by using steel instead of iron may be said to be about 12 per cent. on the weight of hull, or about 175 tons. This saving renders possible a large proportionate addition to the coal supply. The distribution of the weights in this vessel is as follows when expressed as percentages of the displacement:

	Per cent.
Hull	38.5
Rigging, armament, stores, and general equipment	13.5
Engines, boilers, &c	28.0
Coals	20.0
	100.0

The percentage for weight of hull will probably seem high to gentlemen conversant only with merchant ship construction; and it may be well to remark that in a war ship, carrying guns and torpedoes, minutely divided into water-tight compartments, and elaborately fitted throughout with reference to her special service, a large amount of weight is charged to the hull, to which there is nothing corresponding in the merchant ship. The fairest method of estimating the saving of weight effected by using steel is, therefore, that I have adopted—comparing the *Iris* with another iron-built war ship of nearly the same dimensions and displacement. But it may be interesting to add that in looking through the details of weights for the *Iris* I find that over 200 tons of materials have been worked into the hull for fittings, subdivisions, &c., not required in a merchant ship, and if this weight be deducted, the hull absorbs only about 32 per cent. of the displacement, and it could be built, no doubt, with that weight of sufficient strength.

As a matter of interest only, illustrating the vastly different conditions under which a torpedo boat is driven at a speed equal to that of the *Iris*, the following table is given:

	Per cent. of the displacement.
Hull	38
Equipment and coals	22
Engines, boilers, &c	40
	100

To drive the *Iris* at her full speed of 18.6 knots on the measured mile about 2.3 indicated horse-power per ton of displacement were required. In the torpedo vessel over 14 indicated horse-power per ton are expended.

The *Iris* is a sea-going ship, fully equipped, and capable of steaming nearly 7,000 knots at a speed of 10 knots on her own coal supply; but the torpedo vessel is in no sense sea-going, and carries only a limited coal supply and equipment.

The *Iris* gains upon the torpedo vessel in these various particulars, chiefly because of her much greater size, but when she is compared with other fast sea-going steamships her size is very moderate, and her speed is much in excess, in consequence of which the expenditure of power in proportion to displacement is unusually great. This statement is not likely to be questioned by any one familiar with steamship design. The length of the *Iris* is also very moderate when considered in relation to her maximum speed; but it is necessary to remember that she has absolutely no straight of breadth amidships, and consequently has as great a length of entrance and run as many merchant steamers 80 or 100 feet longer than herself. This is, no doubt, much in her favor when steaming at speeds approaching her maximum.

No sea-going merchant steamer having realized the measured-mile speed of the *Iris*, I cannot illustrate the matter by comparing their performances with hers. But turning to Mr. Froude's paper "On the comparative resistances of long ships" in the Transactions for 1876, and having regard to the experiments on the model of the *Merkara* (built by the Messrs. Denny) a comparison may be made between her probable performance if driven at 18 knots by twin-screws and that of the *Iris*—18 knots being about the full speed which the *Iris* may be expected to attain when fully laden. For a speed of 18 knots Mr. Froude gives:

Resistance of *Merkara* (about)	70,000 pounds.
Corresponding effective horse-power	3,870 H. P.

This is for the naked hull; if she had twin-screws, the external struts and tubes would cause an increased resistance, which would, however, be more than counterbalanced by the greater efficiency of the twin-screws. Using our data for the *Iris* in order to pass from the net effective horse-power of the *Merkara* to her probable indicated horse-power for 18 knots, I find that the ships compare about as follows, when the *Merkara* is brought to the actual load displacement of the *Iris*:

Merkara (probable)	8,500 I. H. P.
Iris (actual)	7,500 I. H. P.

At the measured mile the *Merkara* attained 13 knots with 2,000 indicated horse-power when driven by a single screw; and the *Iris*, although of 690 tons less displacement at her trial draught (3,980 tons as against 3,290 tons), required about the same power for an equal speed. The *Mekara* has a wetted surface, which is only about six-sevenths the wetted surface of the *Iris*, although her displacement is one-fifth greater, her form being well adapted for the moderate speeds at which she was intended to work; for which speeds the frictional resistance due to the wetted surface, exceeds three-fourths the total resistance, according to Mr. Froude's estimate. It is of course necessary to remember that the engines of the *Iris* develop less than one-third of their full power at 13 knots, while the *Merkara's* engines are at full power; but allowing for these differences, the figures now given illustrate the influence which the length of entrance and run have upon the expenditure of power at high speeds, and show that absolute length, if obtained by middle-body, with only moderate lengths of entrance and run, may not be a source of economy at very high speeds. Mr. Froude has fully stated the case in his paper published in the Transactions for 1877. I have referred to it only as bearing upon the dimensions chosen for the *Iris*.

It may be interesting to add a brief comparison of the measured-mile performances of the *Iris* and the *Hecla* torpedo depot-and store-ship, of which Mr. Barnaby gave a description in his paper on "Armor for ships," read yesterday. The *Hecla* is 392 feet long, 39 feet broad, and on her trials had a displacement of 5,760 tons. She attained a full speed of 12 knots with 1,760 horse-power, and a speed of 8¼ knots with 645 horse-power. For equal speeds the *Iris*, of 3,290 tons displacement, requires 1,670 and 670 horse-power, respectively. The apparent gain for the *Hecla* is very considerable, and it is necessary to note the fact that she, like the *Merkara*, being designed for working at moderate speeds, is admirably adapted for the purpose, having a small ratio of wetted surface to displacement as compared with the *Iris*, which is designed for extraordinarily high speed. The case stands as follows:

	Square feet of wetted surface.
Hecla	4.2 per ton of displacement.
Iris	6.7 per ton of displacement.

The expenditure of engine power for 12 knots' speed may be expressed by the following ratios:

	I. H. P. (Displacement.)	I. H. P. (Displacement.) $\frac{2}{3}$	I. H. P. Wetted surface.
Hecla	.305	5.5	.073
Iris	.507	7.5	.076

Of these three ratios the first will probably be considered most important in a commercial sense, but the third should not be omitted from consideration, because the adoption of an extremely fine form, adapted for very high speeds, involves the high ratio of wetted surface to displacement which has been stated for the *Iris*. The foregoing comparison requires to be supplemented by other considerations. First, the engines of the *Hecla* were developing their full power for the speed of 12 knots, whereas the engines of the *Iris* were developing less than one-fourth of their full power. Secondly, the screws of the *Iris* are adapted to the full power of her engines; and for comparatively slow speeds, such as 12 knots, this involves a greater expenditure of power in overcoming screw-friction than is required in the *Hecla* to overcome the frictional resistance of her screw. Experimental data for the *Iris* enable it to be stated that at 12 knots the waste of power on screw-friction, and on the constant friction of the very powerful engines, amounts to 500 horse-power, at least, out of 1,670 horse-power indicated. No corresponding data are available for the *Hecla*, but at the very outside the corresponding waste of power in that ship cannot be supposed to exceed 300 horse-power, out of the 1,760 horse-power indicated, and the waste would probably be less. Making these deductions, we have 1,460 horse-power for the *Hecla*, and 1,170 horse-power for the *Iris*, available to overcome the other factors in the gross resistance, such as the net resistance of the hull, augment due to the action of the screws, load-friction of the engines, &c. The expenditure of this power (remaining after the waste work on screw-friction and constant friction of the engines has been allowed for) stands as follows for the two ships:

	H. P. (Displacement.)	H. P. (Displacement.) $\frac{2}{3}$	H. P. Wetted surface.
Hecla	.25	4.5	.06
Iris	.35	5.3	.054

These figures are suggestive. They illustrate the penalty which a ship designed for very high speeds has to pay when steaming at moderate speeds, as compared with a ship designed expressly for such moderate speeds. The latter gains in having less powerful engines, less waste work on engine friction and screw resistance, and less wetted surface in proportion to displacement. But, on the other hand, if the forms which are so well adapted for moderate speeds, are carried out in vessels intended to be driven at very high speeds, they may prove very wasteful of power as compared with finer forms, like that of the *Iris*.

In determining upon the dimensions and proportions of the *Iris* it was necessary to consider not merely possible economy of engine-power, but her special requirements as an unarmored war-ship. The chief requirements additional to those of speed and coal-endurance were:

(1.) Protection of the engines and boilers by placing them under water, and within the side coal-bunkers.

(2.) Provision of sufficient initial stability to enable the vessel to be safely navigated when her consumable stores were exhausted, or when compartments had been bilged in action.

(3.) Moderate length, to secure handiness.

These special requirements, and her unusually high speed, completely separate the design of the *Iris* from that of the swiftest ocean-going merchant steamers, and render it practically useless to endeavor to argue from one class of ship to the other. No one at the Admiralty would be disposed to recommend that the forms and proportions of the *Iris* should be imitated on a larger scale in the merchant service. Nor, on the other hand, does it seem probable that a swift dispatch vessel fulfilling the above requirements could be built satisfactorily on the model of the existing merchant steamers, having, say, ten beams in the length. These proportions are, no doubt, well adapted for merchant steamers carrying heavy cargoes, with centers of gravity low down in the ships, and freely using water or other ballast to preserve their stability. But in a vessel like the *Iris* the vertical distribution of the weights is very different; and if an armed dispatch vessel were built on the merchant steamer model, of the same displacement as the *Iris*, but with, say, ten beams in the length, I am of opinion that sufficient initial stability could only be secured, even in the load condition, by using ballast. This is the conclusion I have reached after a careful consideration of the particulars of many successful ocean steamers, with which

I have been favored by various gentlemen. Furthermore, to the best of my judgment, it seems certain that even if any economy of steam-power could be realized in the longer and narrower dispatch vessel as compared with the *Iris*, the consequent savings in weight of machinery and coals would be much more than counterbalanced by the weight required for ballast, and the additional weight put into the hull, if this vessel were to be made as strong and as stable as the actual *Iris*.

It may be said that the *Iris* is unnecessarily strong against principal strains, or that she is unnecessarily "stiff" against heeling forces. In reply, I need only say that with a few exceptions—such as the upper-deck plating—the provision against local strains and for minute water-tight subdivision, as well as for a reasonable amount of wear and tear, has regulated the scantlings chiefly, and caused the strength against principal strains to be so ample. Moreover, taking into account the differences between merchant-ship and war-ship construction mentioned above, and the increased strains incidental to the adoption of greater lengths and greater ratios of length to breadth, I am inclined to believe that it would be no easy matter to build a new and longer *Iris* with a less weight of hull than that of the existing ship, and with sufficient strength. As regards subdivision and "stiffness," it is clear that in a ship intended to be capable of fighting there must be a margin against loss of stability through compartments being damaged by gun fire or ramming, which may reasonably be dispensed with in a merchant steamer.

A minor difficulty that would have to be faced in a narrower and longer ship of equal displacement with the *Iris* would be the stowage of the hold. This would require to be entirely rearranged as compared with the *Iris*, if the engines and boilers are to be kept under water. And accepting the possibility of doing this by occupying a greater length with the machinery and boilers, it will be evident that coal protection equal to that in the *Iris* could only be given to the longer ship by carrying a greater weight of coal. The greater length of side to be protected necessitates this, or the acceptance of a less thickness of bunker if the same weight of coal is carried as in the *Iris*.

In making these remarks on the dimensions and proportions of the *Iris* I would not be supposed to assert that the ship is incapable of improvement in these respects; my sole object is to indicate the special character of the service for which she was designed, and the manner in which other requirements have been met concurrently with the attainment of high speed under steam. If still higher speeds were desired in future vessels, or if a larger coal supply were required, it is likely that advantage would result from an increase both in length and in the proportion of length to breadth. Greater length is, of course, advantageous in decreasing pitching and enabling speed to be maintained in a sea-way. On the other hand, it must be accompanied by some decrease in handiness, although this might have to be accepted in order to secure higher speed and greater coal-endurance. But I am disposed to think that all the requirements in armed dispatch vessels for some time to come may be met without approaching the lengths, or ratios of length to breadth, now adopted in many of the largest sea-going steamers of the mercantile marine.

DISCUSSION.

Mr. THORNYCROFT. My lord, I would beg to make a few remarks upon this paper, particularly as I feel interested in some of the statements. The proportion of weight of hull and several other particulars given correspond so very nearly with those of boats of my firm, and the description given of the enduring power of the coal supply, that I should like to make a few observations to account for what I do not imagine is meant to depreciate that endurance, but still it would lead one to believe that we can only carry sufficient coals for a run of a few miles. Therefore I beg to make this statement, that in sending boats from the Thames to Portsmouth, and from Chiswick to Cherbourg, we find not the least difficulty in carrying twice the amount of coal required to make the voyage, and in running from the Thames to Portsmouth the coal consumption is about 2½ tons, the coal supplied being 5 tons; and the speed maintained is from 10 to 12 knots. Several French boats in going to Cherbourg encountered heavy weather. Of course heavy weather in the channel for so small a vessel meant a great waste of coal, but in those cases I think a run of from 200 to 400 knots could be made at a moderate speed with these vessels. With regard to Mr. White's paper, it seems to me to show that the greatest care has been bestowed on the design of the hull. And the wide proportions used giving such good results as to speed seems (I am very glad to believe) to show that Mr. Froude's theory as to the width of the ship, a wide ship with a small surface, gives better results than a long ship with a larger surface. The comparison of the *Iris* and the *Hecla*, in which the fine form of the *Iris* is somewhat handicapped by the large friction of the heavy machinery when worked at a low speed still giving a good comparison, is very interesting, and I am sure that in this paper giving the details of the structure, and Mr. Wright's admirable paper on the performance of the screw, we have such excellent information with regard to this ship that if we could have, through the mercantile navy, similar complete information as to what was really built, it would be a very great advantage to everybody, because ships would thus be able to be built with great improvements. Builders who were formerly, no doubt, jealous of other firms knowing exactly what they did, might be influenced by it, and everybody would gain, by the sound knowledge of what constitutes a good ship being general.

Mr. WILLIAM DENNY. My lord, would you permit me to say a few words, as Mr. White has referred to the *Merkara*, tried by my firm? I quite agree with all the remarks which Mr. White has made as to the difference between these vessels, and which he has made very justly. The *Merkara* was a vessel with 100 feet of straight amidships, and although her design was suitable enough for the ordinary speed at which she was driven, 11 knots, it was decidedly unsuitable for her being driven faster, because her fore-body and after-body were too short. Mr. Scott Russell taught us that theory long ago, and at the present moment many of our speed calculations are based on measuring the length of the fore-body and the after.body. I must acknowledge to Mr. Scott Russell, with real pleasure, that we have come round to that. Mr. Kirk has invented an ingenious method by which this theory can be roughly applied. I am much astonished at the results obtained in the *Iris* construction. The thinness of the material is something beyond what I would have expected, and I am sure that I may express the admiration of builders at the skill with which the admiralty has done this work. Mr. White has struck the true key-note of construction in the *Iris* in massed framing. It resembles the construction of the *Great Eastern*, only with intermediate framing for the local support of the skin. Notice those Z sections of steel—I wish exceedingly that iron-makers would roll them for us at a moderate rate—they have been most beneficently used there in distributing the strength of the transverse bulkheads. With reference to steel, I wish to ask Mr. White one question regarding a point which has arisen between Lloyd's and builders. I am afraid Lloyd's have got a little bit nervous lately about steel, and are a little too anxious, and an order has been promulgated that if we work a piece of steel in the fire that it is to be annealed afterwards, and wholly annealed. I do not say that that order is a bad order, but it would have been better if it had been issued with some comment. It will immediately strike you that the most difficult subject of annealing in a ship is the beams. We weld in the beam-knees and finish them. If we are to put the beams into furnaces, we will have to expend a deal of money in making furnaces fit to hold them. Not only that, but I ask you to picture to yourself the appearance of the beam when it comes out.

I would ask Mr. White to give us some information upon this point, because I believe our friends at Lloyd's are open to argument upon it, and do not wish to press a thing that would exclude steel from ship-building yards. We are at present building three steamers of steel to Lloyd's rules, and we find that the maximum saving we can make between iron and steel, building them to Lloyd's rules, is, roughly speaking, between 14 and 15 per cent. That is actual saving as between the scheduled weights. Mr. White says 12 per cent. It would be well that we should have a definition of what the percentage is taken on. We took it upon the gross invoiced iron and steel used in the hull. I was wondering whether Mr. White does not take it on the woodwork in addition. If he does, a totally different interpretation of the figures arises. Mr. White has invited us to compare a steamer of the merchant service with a steamer of the admiralty service. It is with no wish to depreciate in any way any steamer of the merchant service that I wish to point out to you that I do not think the admiralty should have taken the *Hecla* as the representative of a steamer of the merchant service. There are one or two points in her which would not be in an ordinary steamer of the mercantile service. Of course there is the greater subdivision of the hull which is due to Mr. Barnaby, which greater subdivision, I am happy to say, is spreading in this country. We are at present builing three steamers subdivided in that way without regard to any special admiralty wants, but because we believe it is good as a matter of safety. But there are points in this steamer that are not due to admiralty influence, and which would not be found in an ordinary merchant steamer. Referring to Mr. Barnaby's remarks yesterday on the height to which the coal had to be piled up in the *Hecla* to protect the engines, any one looking at those engines, and knowing their power, must see at a glance that it is totally unnecessary that the engines should be so high. Two cylinders will do work thoroughly economically up to 3,000 or 4,000 I. H. P., and therefore the piling up of the coal at that point is not an inherent quality of a merchant ship, because an ordinary merchant ship would not have engines with four cylinders that would require the coal to be piled up to anything like that height. Another point in which an ordinary merchant ship would come nearer the admiralty ideal than the *Hecla* is this: If you refer to Mr. White's able *Manual of Naval Architecture* (which I think should be read by every ship-builder in this country), you will find that one of the best portions of it is upon the question of cutting away the gripe. Mr. White informs you that by doing this you have many disadvantages for one advantage, that being increased turning power. But Mr. White has pointed out that an increased size of rudder is sufficient to attain this, and with the enormous mechanical power we have, both hydraulic and steam, there is no necessity for sacrificing the gripe. What you lose by cutting away the gripe of a ship is, first of all, form; secondly, you lose what is a most important admiralty requirement, steadiness. The flat part of the gripe is a great help in steadying a ship. Now that I have spoken about this point, I will touch on another, in which the *Hecla* is not a fair representative of an ordinary merchant ship. It is this: If any of you will look carefully at the position of the coal and the engine and boilers, you will see that the center of gravity of the total amount of coal in that ship must be considerably behind the center of buoyancy, and that means that when the *Hecla* goes to sea, if she burns out all that coal, it will change her trim to the disadvantage of the propeller. That is a point which I think in all merchant steamers, or most of them, has generally been considered.

We apply a longitudinal metacentre calculation, for which we owe the utmost thanks to Mr. Barnes, who has made it easily workable, and we place our coal in the ship so that, if possible, we shall run on an even keel throughout the voyage.

Mr. William John. My lord, Mr. Denny referred to the center of gravity being over the center of buoyancy. I think he must have meant over the center of gravity of the load water-line, so that the ship should rise and fall without altering the trim.

Mr. William Denny. They nearly correspond.

Mr. William John. Another point that was referred to was the annealing of steel required by Lloyd's Registry. Perhaps I may be allowed to explain the matter. It is not that every plate and every angle has to be annealed, but when you heat one end or corner of a plate to flange it, or anything of that kind, you must heat the whole of the plate afterwards to allow it to cool uniformly. The reason for it is this: It has been found over and over again with boiler plates which have been heated at portions of their area that they afterwards, in a most mysterious way, cracked when there was apparently no earthly reason for their cracking, even when men were carrying them in their hands—they have cracked off, and the only reason I have heard for it is that between the heated portion and the cold portion there is set up a state of initial stress, which makes it more or less dangerous to use it unless it has been reannealed. That is the reason why the committee of Lloyd's have become cautious—Mr. Denny thinks too cautious, but I cannot agree with him in that opinion. I think it is a necessary caution until we know more about this material. I would refer to one or two points in the construction of the *Iris*. The *Iris* resembles in construction some of the modern merchant ships far more than most of the ships in the government service, but I may say at once that she is considerably lighter in scantling than a ship of her size would be in the merchant service. Her plating is thinner, and the bottom in a merchant ship of her size would probably require another longitudinal; and in addition to the bracket system, which is four feet apart, we should require an intermediate frame to give additional strength and support to the outside plating. That is necessary. It may not be necessary in the *Iris*. I do not wish for a moment to say it is necessary in the *Iris*. The *Iris* may not have to do the work, and may not have the knocking about that a merchant ship has. For instance, it is not at all an unusual thing for a merchant steamer coming out from New Orleans to bump on the bar, or to touch the ground in other places, and I think they require more local strength than is given to the *Iris*. There is another point that occurs to me, which is this: It is difficult to criticise in detail drawings which we have only seen for a short time, but some of the Z irons, for instance, and some of the angles, are of sizes we very seldom meet with in the merchant marine; and I think we should hear a good deal of outcry if they were put forward by us, because they are not common, and we go as much as possible for common and ordinary sizes. If you go into Z irons and vary your construction from compartment to compartment, by fitting different angles at the ends of the ship and the coal-bunkers, and again in the engine space, you introduce complication which leads to cost, and very heavy cost. I believe, in the case of the *Iris*, the cost of the hull was something like £90,000. Now a merchant ship of her size would certainly not cost for the hull more than about £30,000, with heavier scantlings, and therefore I cannot help thinking that the complication is unduly costly, although perhaps some complication is necessary in a war ship—at least in a ship of war that is to be subdivided as shown on this plan. But, obviously, the merchant marine could not follow a construction of that kind, which might entail double or treble the cost. I should say that possibly and probably the great cost of the *Iris* would be due in part to the fact that she was the first ship built of steel, and probably the steel was much higher in price then than it is now, so I do not wish to press the point at all as to the exact figures. But it is a fact that the complications which I see in the double bottom there are more than we should find in a merchant ship, and I think if you were to follow it you would run up the cost in a way that merchant ship-owners would not stand.

Then another point which occurred to me when Mr. White was reading the paper is with reference to the double bottom, and the use the double bottom is put to, and it has reference rather to the design than to the construction of the vessel. We know that in a war ship, where you have to carry weights high, you must have more beam than you require in a merchant ship, and Mr. White has said in his paper that one of the reasons for keeping the beam of the *Iris* so great was to give her sufficient stability when the vessel was light. It occurs to me that the double bottom might be used with advantage as a water ballast tank for the ship when she is in the light condition, and you might be able to reduce the beam, and perhaps—I do not say you necessarily would—you might get greater speed. You might reduce the resistance, and reduce the amount of engine power required for driving the vessel, which is a most important element, because it affects the coals and everything else. I know from former experience in the government service the different points of view from which a double bottom is looked at. A double bottom is fitted in a government ship almost entirely for safety. Now a double bottom is fitted in a merchant ship, not for safety at all, or at least not for safety as a primary consideration, but it is fitted for commercial purposes, for the purpose of water ballast. I know that the constructors of the navy are perfectly well aware of the use to which water ballast can be put. But it is well known that in the minds of officers of the Royal Navy there is a dislike to the use of water ballast, and I do not think that water ballast has ever been used in a government ship as it ought and might be used, and as it is used in the merchant marine. There was a prejudice against water ballast in the merchant marine, but the commercial advantages of it were so great that owners compelled their captains to use it commonly and frequently as a matter of course, and the prejudice in the minds of naval officers, so far as the merchant marine goes, against water ballast is entirely swept away. I think it might be introduced into the Royal Navy, and that some very valuable advantages might be gained by a more extended and liberal use of water ballast, by their availing themselves of the double bottoms which have been fitted for the purposes of safety and for other purposes.

Mr. J. D'AGUILAR SAMUDA, M. P., V. P. My lord, I regard the paper which has been read by Mr. White upon the *Iris* as one of the most valuable acquisitions this session. We can scarcely have a more important subject brought before us than is dealt with in this paper—that is, the introduction of steel upon a large scale in the marine, in this instance in a shape which might be a type to start with, both for commercial as well as for admiralty purposes. I am one of those who believe, and have for a long time believed, in the substitution of steel for iron. Anything which brings that carefully before our consideration, and especially anything which brings so excellent an example as this before our notice, must have wide and beneficial results. Now I may be permitted in starting to say that generally I approve entirely of the description and construction and the arrangement of this ship. But I want to point out differently from that which appears to have fixed the attention of Mr. White, and certainly in opposition to the observation of the last speaker, that I do not think steel has now, or ever has had, a fair consideration at the hands of Lloyd's. I believe that Lloyd's have never treated it in a proper way, and I believe they at the present moment do not at all realize the advantages the public are being deprived of by the course they are taking. Now I begin by stating that as long as twenty years ago I was engaged in building steel ships, and at that time one of the conditions which was laid down by the company I was engaged for, which was a general one, ranging over a large number of vessels, was that I was to obtain Lloyd's certificates for the ships I was building. A case arose in which it was impossible to carry out the conditions that were required unless steel was used. I did not hesitate to use steel, though I had to pay for steel at that time £50 a ton, and in some instances even £60. But when I went to Lloyd's to enable me to give effect to the classification condition I had entered into, and without considering that this trouble would come upon me, they resisted the matter altogether, as being wholly and entirely beyond their province. They would do nothing with it, and I think I am not misrepresenting them when I say that the conditions they wanted to impose upon me would practically have deprived me of the power of building a ship at all. I think I am right in saying that they wanted to impose on me the necessity, although I should not like to be positive as to it now, of putting exactly the same thickness of steel that they in their rules at that time were using for iron. Of course I was compelled to disregard Lloyd's altogether, and I arranged to build the ship without. But Lloyd's have acted on a wrong principle altogether, and they are acting now with steel vessels upon the same principle. Now the wrong principle they are acting upon is this: Ever since they have been able to grow in the knowledge of building iron ships they have always laid down their rules from time to time to meet the case of the worst description of iron being used in their ships, and they have never made any difference, nor realized that they might have had a very considerably better state of things existing in the mercantile navy if they, instead of depending upon brute strength—I will not say brute strength, but on thickness, which did not give them the brute strength they required—had made their rules compatible with improved quality. I do not hesitate to say that was at the root of all mischief that Lloyd's began with, and are keeping to at the present time. They go upon this principle: That as people, for the sake of decreasing the price, will accept what is called ship plates—the most damaging name that ever was, and the most damaging material that ever was used in ships, and that never has been able to find its way into my yard, or, I believe, anybody's yard who has any regard for the quality he puts into his ships—they take that as their standard, they make every good ship-builder increase his thickness, until he comes up to the thickness they require to be used of this bad quality of iron, and then, when you come to steel, they make a reduction in thickness in steel which they think is sufficient, taking it in comparison with this inferior iron. In this way they at the present moment make some rule—I think I am right in saying they will not allow more than a reduction of one-fourth in the steel compared to that which they have in iron; and compared to the stuff which they allow to go in and be called iron, one-half would be stronger of the good cast or Landore steel made at the present day, but compared with the good iron which people who know what they are about desire to use in their ships, there ought to be a reduction of at least one-third. I do not at all wonder that in vessels of this description they are not wishing to go too much in advance of the time, and that those who are responsible for the construction of the *Iris* and *Mercury* might in some degree have limited their steel in thickness to approximate with Lloyd's rules. But, passing from that, I would venture to say there are some other things in connection with this vessel which I wish to speak about. I want to allude a little to the process of annealing that Mr. Denny called your attention to. This annealing process, again, is put forward in a manner, and with an authority, which I venture to think Lloyd's have no right to do. My impression is that all institutions like Lloyd's are bound to make themselves inspectors, and not directors. It is the greatest mistake, and the greatest misfortune, for naval architecture when these people set themselves up as teachers.

Now they talk about annealing. In all the vessels I have alluded to, which were built twenty years ago, and are going at this present day as well as they did at first, very little heating, and no annealing, was used. To talk about annealing beams is the most absurd thing that can be supposed. If a beam was attempted to be annealed, instead of curving in the direction of the deck, you would find it curving in exactly the opposite direction. In bending beams they are bent in the opposite direction to that which they are required to finish in, due allowance being made, because by observation and practice it is known they will take the opposite form, being pulled so in consequence of the difference in contraction that takes place at the bulb and thin edge. These you are to put in the fire, and destroy that which you have carefully arranged. It is too ridiculous to talk of.

Then I wish to say a word with regard to the observations which have been made about double bottoms. I do not agree with them at all. In the first place, allow me to say that there is a great mistake in supposing that advantage is not taken of the double bottoms in ships of war to make the double bottom water ballast carrying tanks. I have myself built a very large number of iron-plated ships, and in every single instance they have been made so that they can be used as water ballast tanks, and in making their journeys from here to the different countries they have been built for they have almost invariably been used as water-ballast tanks. But I consider the double bottom is an extremely scientific and good arrangement. You do not increase the weight you use in the ship in any degree whatever comparable with the strength that you get by introducing it, and therefore it is a movement in the right direction; but again, if it appears with Lloyd's to clash with their rules, I should not wonder if you find that it is interfered with, and they will either resist it altogether or attempt to make you subscribe to some rule, so that you shall not have their classification if you adopt it. Now I turn from this, which is not a pleasant subject, but I think it is so important that I venture to press it on the meeting, because I think it is high time that constructors were left a great deal more to themselves to produce what they think right, and that Lloyd's should confine themselves to their legitimate province of approving what is good, and not teaching people how to make it different from what they desire to make it themselves. I want now to call Mr. White's attention to one matter which is not very important, but I do it with a view of affording the information, if he desires to have it. He says, "No sea-going steamer having realized the measured mile speed of the *Iris*, I cannot illustrate the matter by comparing their performances with hers." If he does not know it, I shall be very happy to give him the particulars. I, myself, more than fourteen years ago, built a vessel of the same size as the *Iris*, or larger even, which has gone at greater speed than the *Iris*, and I shall be happy to furnish him with full particulars so that he can make his calculations and add them to these valuable notes which he has been able to lay before us. The name of the vessel is the *Mahroussee*, a vessel built for the Viceroy of Egypt, and she attained on a measured mile something like 18.6 knots; that is more than the speed which he speaks of.

Mr. N. BARNABY, C. B., vice-president. My lord, I think the difficulty with regard to the annealing of steel may perhaps be got over in the case of the beams if the builders will be good enough to work the beams cold. They will find, as we have found, that steel will submit to a treatment cold that iron will not submit to. We have, for example, found that angle bars of steel which were rather harsh and were giving us trouble, nevertheless submitted to severe joggling cold. It is usual, as every one knows, in the case of iron, to make them hot for that purpose, but our own practice has been whenever we have put hot work into steel to anneal it. What I want to say is, you will find if you take pains that you will want very little hot work indeed; that your plates, your bars, your beams—everything you have to do, if you like, can be treated by you without your ever putting it into the fire at all; and that is one of the greatest advantages of steel. I must say I think Lloyd's are going cautiously in insisting on this, that if you will put hot work into the material you should for the present anneal. In the case of the beam arms, I think if Mr. Samuda would make an experiment he would discover probably that even if you did it hot, which certainly you need not, the amount of injury done is so slight that it would not need to be annealed. That is easily proved, and need not present any difficulties, as it seems to me, between Lloyd's and shipbuilders. I should like to say one word with regard to a most important question—namely, the cost of a ship like the *Iris*. It has been very rightly said that no merchant ship-builder could undertake to build ships in the way in which this ship has been built; but her great cost is not due so much to the kind of work which you see in the bare hull, it is due to the fittings; and I can appeal to Mr. Harland's experience in that matter with the *Hecla*. The *Hecla* was bought by the admiralty for a sum, including her engines and an outfit, not exceeding much the cost of the hull of the *Iris*, but he had to put a certain amount of work in, to bring her up in a part of her hull to the completeness required in a ship of war; and he well knows how costly it was. If the *Hecla*, finished as she would have been finished by Mr. Harland, had been sent to a royal dock-yard, they would have said, "You have sent us a mere shell." As compared with other merchant ships, she was a splendid ship for her work. In a ship of war, if you go between decks you will see where the money goes. There is no end to it. No one can cry about it as I do, but I cannot see the way out of it. People invent a new mode of attack, and we are obliged to invent a mode of defense, and the new mode of attack we are also obliged to carry. Therefore the ship must always have in what she had before, and we must take the new thing also. Perhaps it may come some day, but at present I do not see how the end of the great expenditure—not on structure or on hull, but on what we call hull; because it is for things connected with the hull, and which are said by naval officers to be indispensable for the efficiency of the ship and their own proper accommodation—is to come. It may be so, but it is difficult for a ship-builder to understand; and I envy those gentlemen who can produce those simple and beautiful structures which we hear about, for next to nothing.

Mr. E. J. Harland. My lord, I have very much pleasure in corroborating the remarks which have just fallen from Mr. Barnaby with reference to the excessive cost for fittings necessary for the various, and I think I may say, multifarious, requirements of Her Majesty's service. With reference to the hull alone, the hull in the merchant service, as Mr. Barnaby has said, may be everything that is desired, but on that has to be grafted an immense number of fittings besides what has hitherto been in use in naval warfare. But now the introduction of the torpedo has introduced a very expensive adjunct. A remark was made in the early part of this morning's discussion with reference to the measured mile. I would simply say that I agree entirely with my excellent friend from Scotland, that for many years the measured mile was not known in Scotland; it was a distance of 16 miles on the Clyde, which was a very wholesome run indeed. I could find no fault whatever with that distance. Occasionally, the vessel might be brought round a little earlier than in strictness they were entitled to do, but that was the only little bit of jockeying that was introduced. I feel that it would be unfortunate in a scientific institution like this, if in our meetings we were to be rather disposed to congratulate than to criticise, and perhaps severely, because a severe criticism, within the range of polite manner and gentlemanly feeling, is the very thing that should be courted here, and therefore I have no disposition whatever to place more credit to those gentlemen who have given so much time to the writing of these papers than they deserve. They deserve an immense amount of credit, because they have evidently exhausted the subject as far as it can be exhausted; but I feel in an institution like this, where the mercantile marine ought at any rate to occupy a very important part of the time, it is not perhaps well for us that we should dwell too long or have too many papers on naval construction—that is, for war purposes—because, after all, the backbone of the country is not our war ships, I hope, but our merchant ships. Now, some reference was made to the *Hecla* as being a very exceptional merchantman. If the *Hecla* had been produced some years ago she would have been considered a marvel. I might almost say that we have been brought to see, within the last few years, that what was once considered to be an anomaly in ship-building, what were called "coffins," have since proved not "coffins," but the life of the commerce of the mercantile marine. I am referring to the long ships. Now, the difficulty which long ships had to contend with at first was what was called their unhandiness. The unhandiness of these long ships is a pure myth. If you ask any pilot going into Liverpool accustomed to these long ships of the modern type, he will tell you he would rather swing one of these ships 400 or 450 feet in length, with the forefoot cut off, and with, of course, a wholesome size of rudder, in the tideway of Liverpool, with the river crammed full of shipping, than one 100 feet shorter without the forefoot cut off.

As to the "grip" of a merchant steamer's bow, you want nothing of the kind. The grip may be wanted in a sailing vessel, where leeway is a question for consideration. But what do you want with grip in a steamer? The flat side of her is grip enough. They know nothing of leeway, and a little bit of canvas spread on her, of which the *Hecla* is a very fair type, is not sufficient to give them any leeway. Then, as to the cutting off: it is an advantage in two ways, quite independent of the matter of steering. Now, take the *Iris*. I do not wish to draw attention to that particular ship, but take the forefoot of any modern shaped steamer, and I undertake to say that if you cut off so much of the forefoot as is represented on the *Hecla*, you will find that you cut off an amount of displacement which would not equal one-fourth or one-fifth of the amount of dead weight on that forefoot. In other words, when we go on board a merchantman what do we like to see? In the rapid Holyhead steamers the first thing the captain did when he went aboard was to shift all his anchors off the forecastle and get them as nearly amidships as possible—and why? Because the paltry three or four tons of weight on the nose of the ship was quite sufficient in driving them at a high rate of speed in a head sea, for the captain to know perfectly well that that amount of dead weight on the very nose of the ship was objectionable. Therefore he ingeniously and properly shifted the anchors to the after-end of the turtle-back, and arranged for them to be let go there. There is far more weight cut off the forefoot of the *Hecla* than the weight of both her bower anchors. Furthermore, if you take the fine entrance of the lower part of any merchant steamer—if you look to the lines of that part of the ship, you will at once say that they are needlessly sharp. You have not made them sharp for satisfaction or for beauty, but it is merely in order to get a sufficiently fine load water line; and still sticking to that forefoot being brought down, you are inevitably brought into extremely fine lines at the forefoot—so fine that I say if you only simply cut that piece off you are removing a useless piece of matter from the bow of the ship which is unnecessarily fine for cleaving water, and is only so much iron to be carried in the most objectionable part of the ship, the bow, when she rises to the sea. With reference to the coal-bunkers, Mr. Denny, who favored us with so many very lucid remarks, is perhaps not aware that the *Hecla*, like many others of the same type of ship, is so arranged that she has what is called a coal-hole forward of the coal shown in the bunkers. Those bunkers shown are merely what are called the bunkers proper, but there is a coal-hole forward of those bunkers which will contain as much coal as will take that ship out to New York without using a single ton of coal out of the bunkers. The consequence is that when she goes on her voyage across the Atlantic, or a similar voyage, she lightens herself forward. We must not take the weight of the bunkers as proper for the center of the vessel; we have to take the whole thing. We take her so that on her outward voyage, taking her own coal out, she lightens forward. That is a very important circumstance. In coming home, as the cargoes pay very much better homeward than outward, she utilizes the coal-hole and other places for cargo. On the return voyage, whilst she has the disadvantage of slightly lightening herself aft, she has the great advantage of the average of westerly winds in her favor. The consequence is that, like all things in naval architecture, if the naval architect enters his profession and follows it out on scientific principles simply, he will make a great mistake, and if he follows it out from a ship-builder's point of view he will make a mistake. He has to be scientific, and he has to be practical, and he has to be something of a merchant. In other words, the result of the whole thing must be satisfactory to everybody, and particularly to the man who pays for the vessel and owns her. We must not lose ourselves in science. I should be the last man in the world to say a word against it, but I think at the present time we are disposed to make too much of what is called education. We are educating our children now above what the probability is they will ever be able to utilize in after life. A shoemaker educates his child to be a doctor, or a barrister, or something advanced, in place of teaching him how to make the very best shoes. I contend that the sons of ship-builders are over-educated, and are apt to lose themselves in figures, because they are very apt to follow the easier course of study, having books and papers before them, and neglect the workshop, and neglect coming in contact with those merchants who have to consider most carefully what class of ships will pay the best. I say if a ship-builder does not combine in his profession all these varied and sometimes opposing forces he will make a serious mistake, and lower the value of his profession not only as a profession but also the value of it to this commercial community.

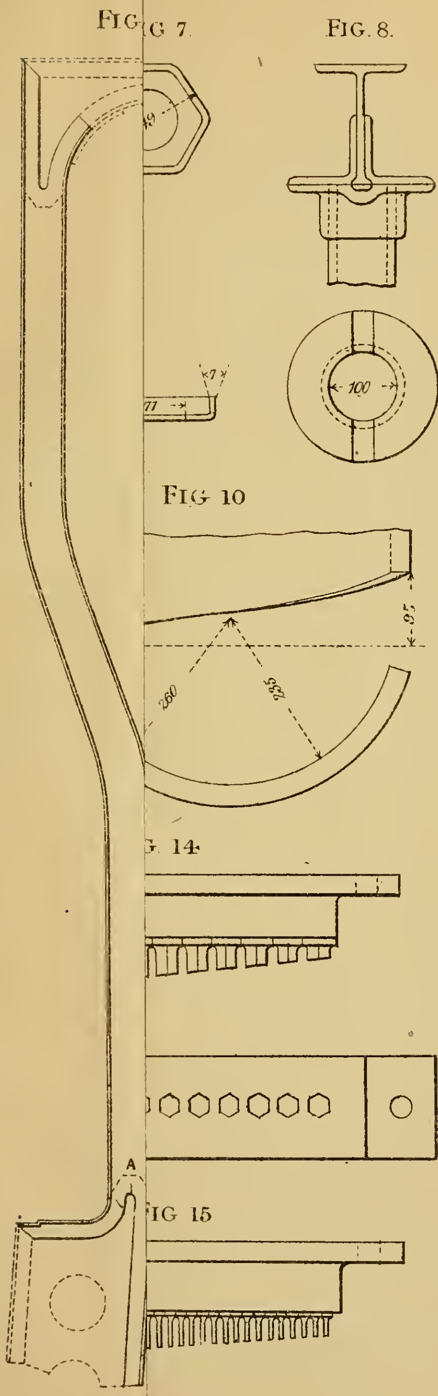
The President. The clock warns me that it is almost time we should bring this interesting discussion to a close; but I cannot call on Mr. White to reply to what he has heard without offering him my congratulations on the discussion which his paper has elicited, which I think must have been gratifying, and very justly gratifying, to him. I wish also so far to intrude upon you in point of time for one moment as to say that I entirely concur, as far as my own individual opinion is concerned, with regard to the immense importance of our mercantile marine which was so justly referred to by Mr. Harland, in the able speech which he has addressed to us; but I think Mr. Harland would admit that in these times of transition in naval architecture it is only natural that an institution of this kind should devote its attention to the construction of ships of war, and I hope he will also join in the opinion which I myself entertain that we cannot come here and discuss paper after paper day after day on the best mode of constructing our ships of war, and of varying the construction, without touching on scientific principles which bear not so directly but most importantly on the interests of the mercantile marine. I hope that I have not said anything unpleasant to Mr. Harland in making these observations upon his able speech, and I hope he may agree with me that in such a discussion as we have just heard we are really promoting the interests of naval architecture at large, whether applied to merchant ships or ships of war.

Mr. W. H. White. My lord, Mr. Harland thoroughly expressed the feeling which I have when he said that in an institution like this we should have more papers bearing on the mercantile marine. I think the secretary will bear me out in the statement that this session there has been great difficulty in getting any such papers; and I may say in personal explanation that I should have been very glad, pressed as I was with other work, not to have undertaken the preparation of this paper, but when it was found in preparing the programme that gentleman from the mercantile marine did not come forward, then the Admiralty and Lloyd's were applied to to see if papers could be obtained to give some information of general interest. I should be only too glad to have the opportunity of studying in detail the performance of those wonderful vessels which Mr. Harland's firm has constructed. I have often thought, if the performances of the series of vessels of the *Illyrian* type, of which the length was gradually increased by adding certain proportions of the beam, could only be put down in detail, we should get a complement to Mr. Froude's experiments on the effect of straight of breadth which would be most instructive. Once or twice I have been on the point of writing to Mr. Harland myself, to ask for the facts, but I have never yet mustered the courage to do so, but I will accept with gratitude Mr. Samuda's offer of the particulars of that very fast ship he spoke of. I believe I am right in saying she was a yacht, and of course in that respect differed from the *Iris*, which is a self-sustaining ship of war. I do not wish to raise the question, but I shall be most grateful to Mr. Samuda for the data if he will give me them. Then, with regard to Mr. Thornycroft's remarks on torpedo boats, I was thoroughly aware of their enormous steaming capacity at moderate speeds, but what I meant when I said that they were not seagoing was in the sense of their being self-supporting, carrying an equipment such as the *Iris* would, which is a vessel which could be absent from port for many months, except when requiring coal. That is the sense in which I meant sea-going, not simply as measured by the power of steaming long distances at moderate speeds. I am fully aware of what Mr. Thornycroft has achieved, and I admire most thoroughly what he and Mr. Yarrow have both shown can be done as to high speeds in vessels of a small size. Mr. Denny's question as to steel Mr. Barnaby has answered, and I think Mr. Denny was satisfied with that explanation.

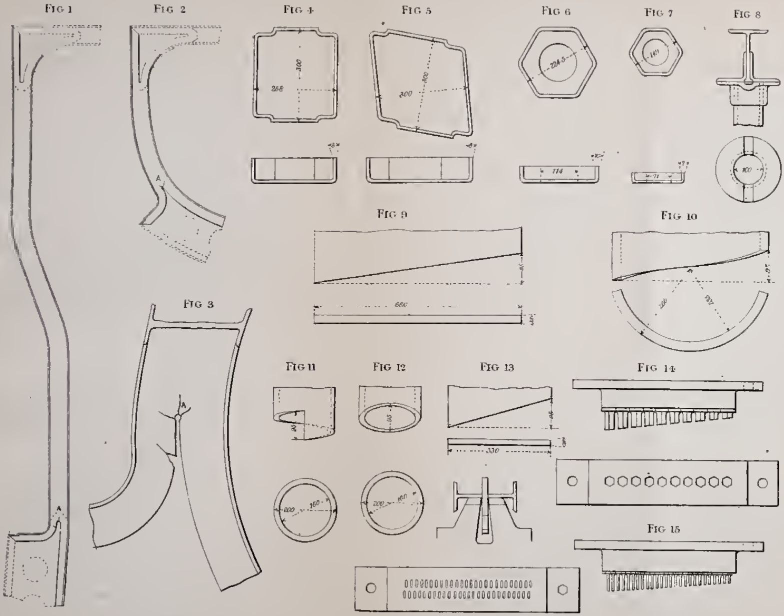
Mr. W. DENNY. There is one difficulty, which is this, that in turning down the end of the beam you require to weld in a piece.

Mr. WHITE. Perhaps I may be permitted to add to Mr. Barnaby's explanation by saying that our own practice has not been to anneal the whole beam in all cases. That is the point which you are more particularly considering. Then as to how the percentages were taken for the saving in weight of the hull. Mr. Denny was quite right in supposing that I expressed the percentage on the footing of the total weight of the hull. Mr. John remarked that by using water ballast in the double bottom perhaps there might have been a diminution of her resistance if her breadth were decreased. I only wish that Mr. Barnaby, the responsible designer of the ship, had said what the history of the design was; but, as a matter of fact, the *Iris* had her beam increased for the purpose of lessening her resistance, and she gained in stiffness, because of the proportions accepted to decrease the resistance—that is to say, for stiffness we could have accepted a less extreme beam than was adopted for the purpose of lessening the resistance. That is the matter of fact. The *Iris* as she stands is a stiffer ship than one might expect. There is no doubt she has a metacentric height in a loaded condition of over 3 feet. I want to draw attention to the fact that in the paper I speak of the stiffness as it affects the margin of safety—the ship has to be knocked about and partly damaged, and the better she starts in stability the better chance she has of sustaining stability. Now, one thing more. The *Iris* is a ship that has to turn at a great speed. Anybody who has looked into the question of turning at a great speed will know that as you increase the speed of the ship with a good metacentric height, you get a considerable angle of heel in the turning. That is another reason why the *Iris* should have good beam. The use of double bottom spaces for water ballast in the *Iris* would be of no service. We do not want the water ballast. We have the means of using it in the *Iris*, because we have a system of flooding and pumping out the double bottom, and if it were needed it could be used for the purpose of trimming or stability. Then as to the cost of hull, Mr. Barnaby has fully explained that, with one exception. He did not mention a thing which Mr. John himself mentioned, and it is an important matter—that is, that the price of mild steel now is very different from what it was when the steel for the *Iris* had to be purchased. In fact, the mercantile marine is now reaping the benefit of the policy which Mr. Barnaby so ably advocated here some five years ago, which led to the use of steel in the hull of the *Iris*. As to the angle-bars (and this is a matter of detail), Mr. John properly pointed out that these bars are of large size. We have, in fact, greater choice of size in the Royal Navy than perhaps the mercantile ship-builder would have. We have adopted the system, as regards both steel plates and bars, of specifying the weights by either units of length or units of area, and the manufacturers work to these units with the greatest ease. Of course with the same sized flanges you may have angles rolled thinner or left thicker, and so get a varying weight per foot. Lastly, as to the resemblance in structural arrangements between the *Iris* and the modern merchant ship, I think that is a matter for congratulation. It shows that those who have given most attention to the matter, both in the admiralty and outside it, have come to the same conclusion—that if you want to get the greatest advantage out of steel that can be got from it, you must use the stronger material in less thickness, and prevent buckling and local strains by an efficient means of support. I think, my lord, those are all the points which I wish to mention. I am extremely obliged for the kind opinions which have been expressed on the paper, and I hope it may be of some service.

To ·ch Dockyards



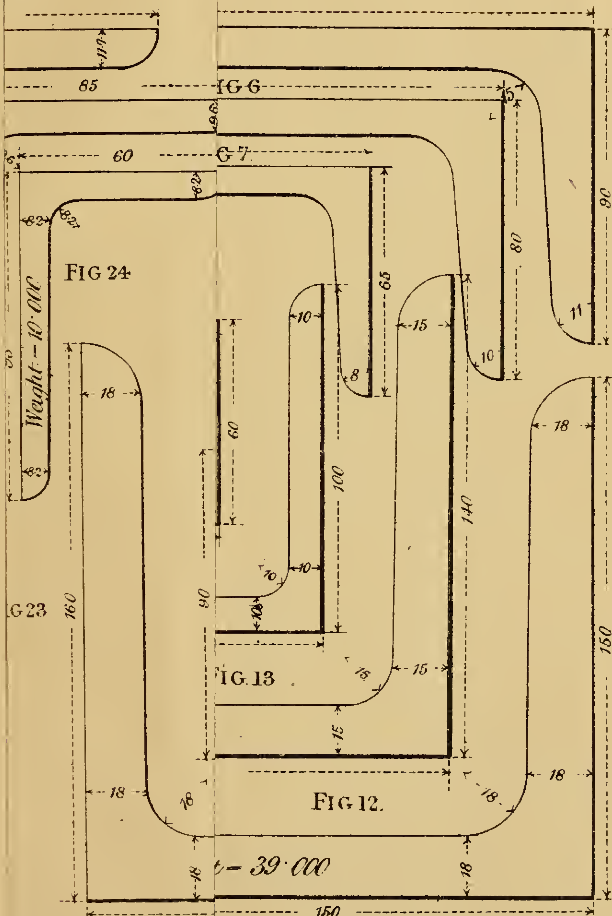
To Illustrate M. Marc Berrier Fontaine's Paper on the Use of Mild Steel for Shipbuilding in the French Dockyards



Scale 1/50 for Figs 1 & 2 and 1/10 for Figs 3 to 15

LOYED IN THE FREN

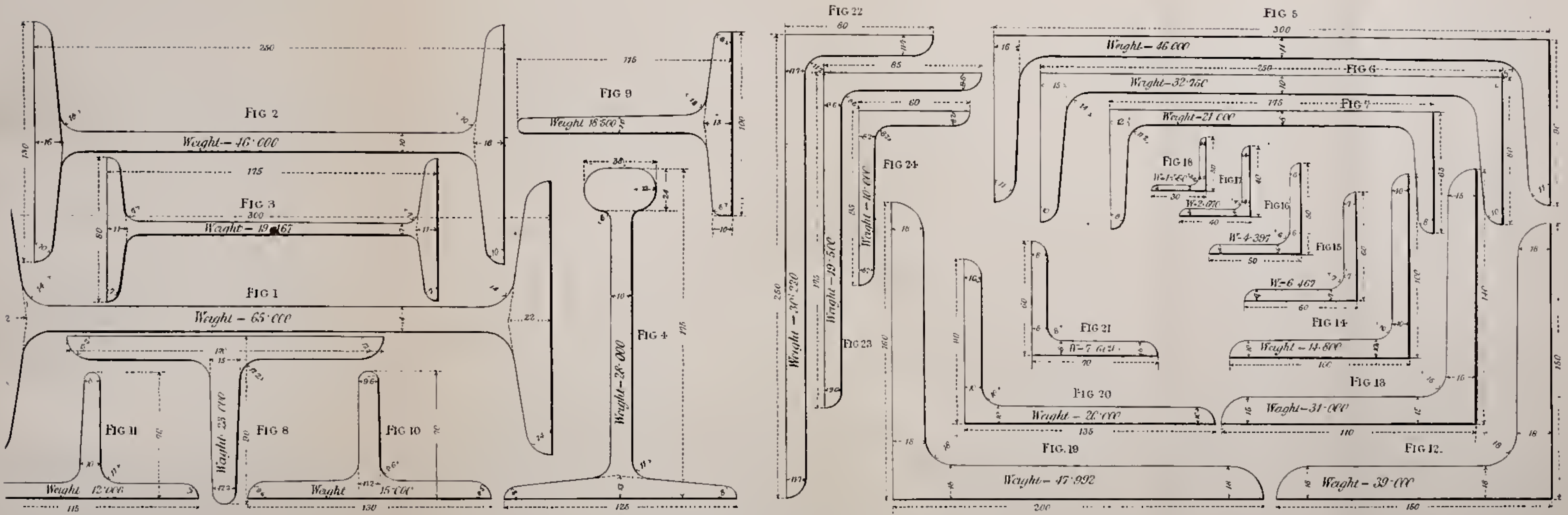
22



...ons are

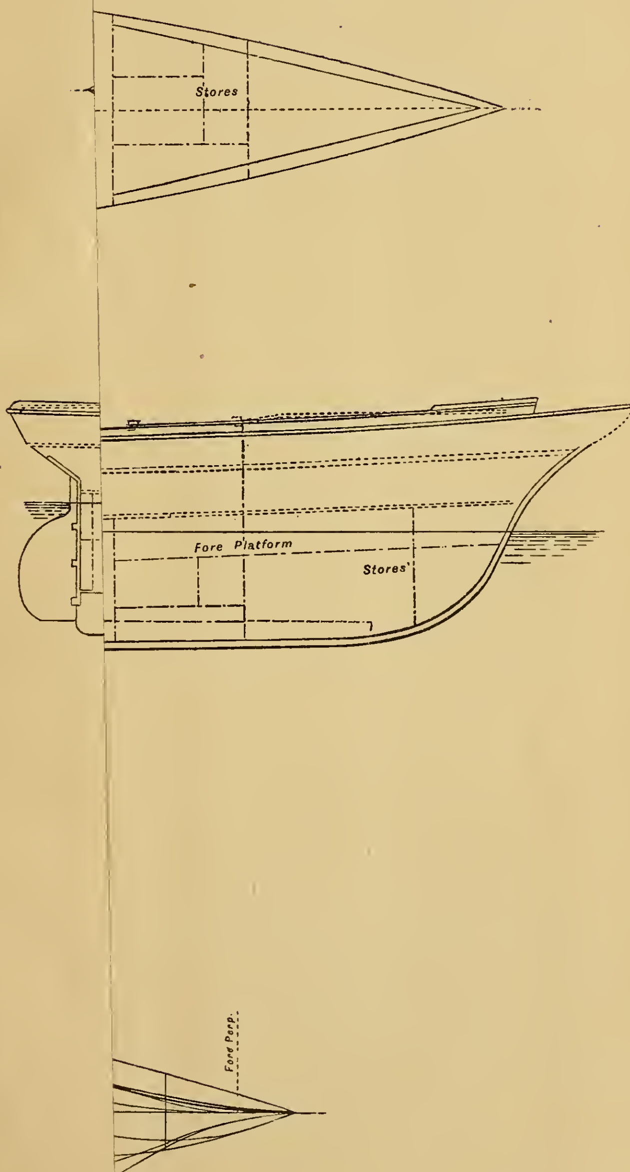
SPECIMENS OF VARIOUS SECTIONS OF BARS EMPLOYED IN THE FRENCH NAVY

SCALE ½ NATURAL SIZE



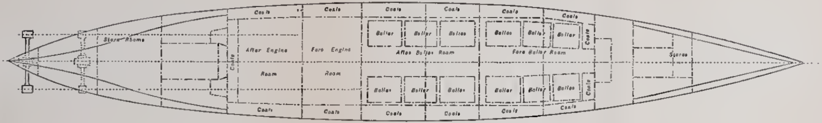
N.B. The Weights marked on the Sections are in kilogrammes per metre run

: of H.M.S. "Iris."

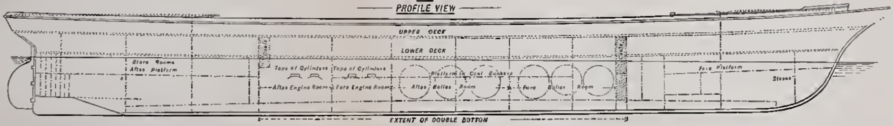


To illustrate Mr. W. H. White's Paper on the Structural Arrangements and Proportions of H.M.S. "Iris."

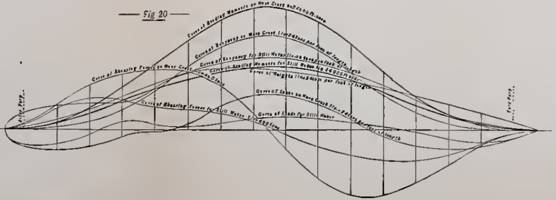
—FIG.1—
PLAN



—FIG.2—
PROFILE VIEW

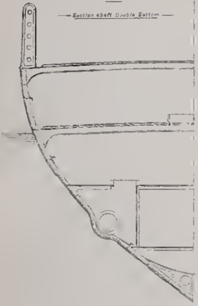


— Fig 20 —

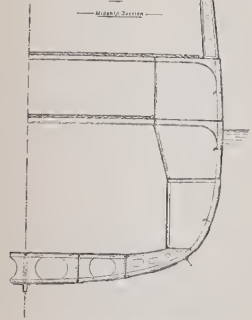


To illustrate Mr W. H. W[illegible] Pa[illegible] on the Structural Arrangements and Propo[illegible] of H.M.S. "Iri[illegible]"

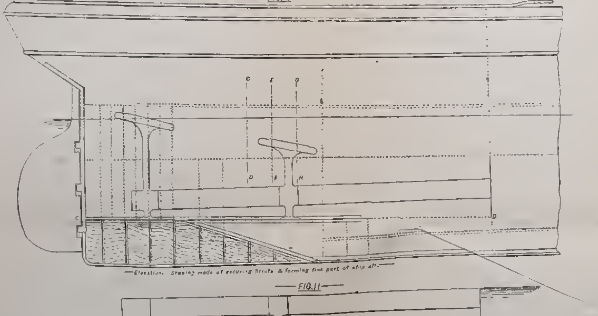
— FIG. 4 —



— FIG. 3 —

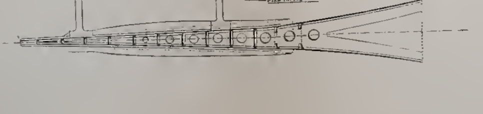


— FIG. 10 —

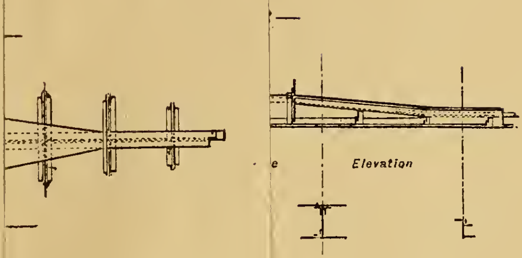


— Elevation. Showing mode of securing Struts & forming fine part of ship aft. —

— FIG. 11 —

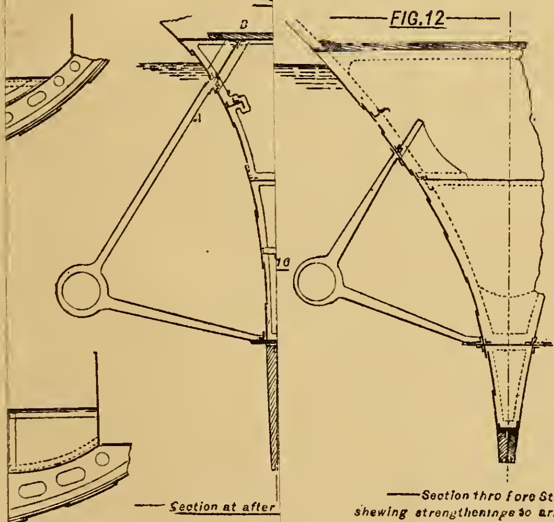


portions of H.M.S. "



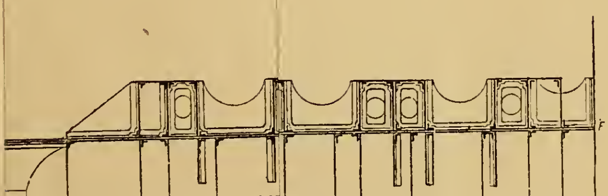
--FIG

FIG.12

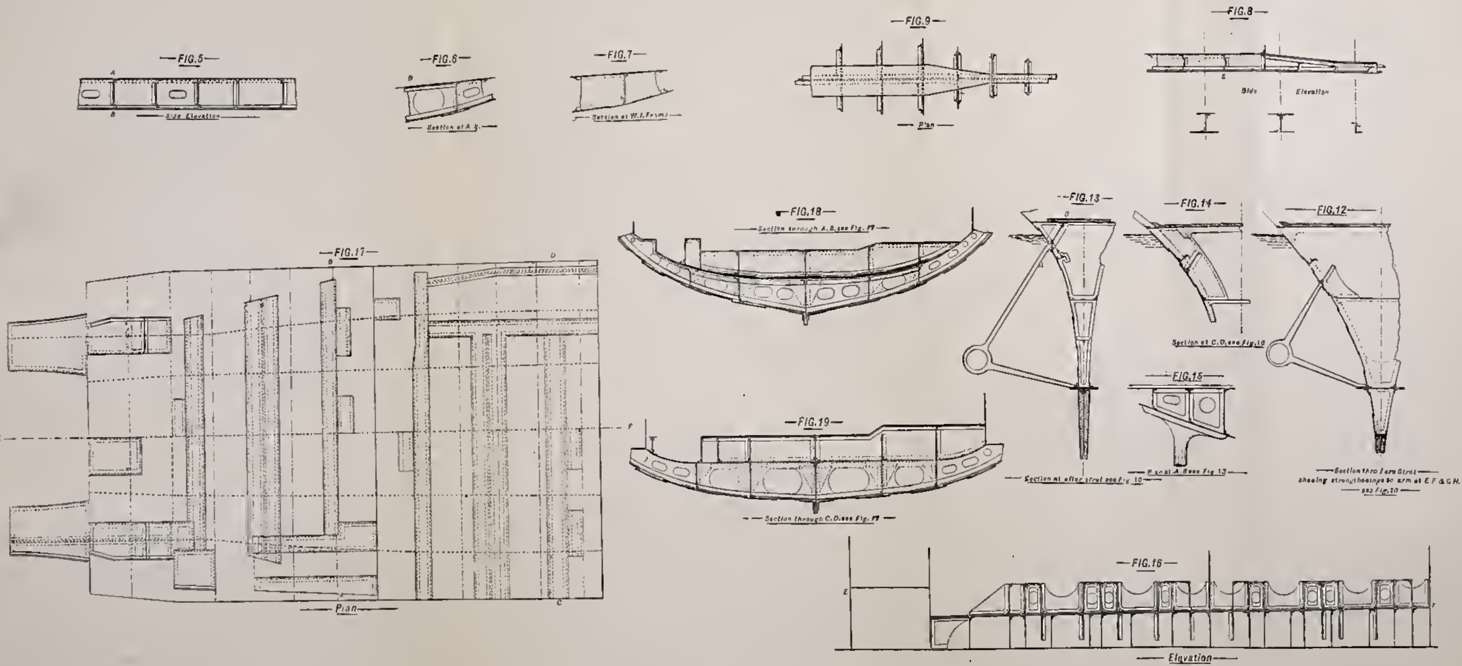


Section at after

Section thro fore Strut
shewing strengthenings to arm at E F & G H.
see Fig.10



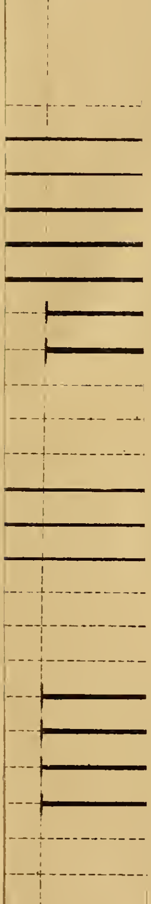
To illustrate Mr. W. H. White's Paper on the Structural Arrangements and Proportions of H.M.S. "Iris."



French Na

square millim

46



COMPARATIVE TABLE of the conditions of acceptance for Plates and Rolled Bars in Steel by the French Navy, the British Admiralty, Lloyd's Registry, and the Underwriters' Registry.

			Thickness	Minimum Elongation per cent.
French Navy	Plates	For Boilers	20 to 30	25
			8 „ 20	26
			6 „ 8	24
		For Ships	20 to 30	20
			8 „ 20	20
			6 „ 8	20
			5 „ 6	18
			4 „ 5	16
			3 „ 4	14
			2 „ 3	12
			1 „ 2	10
	Straps and Butt Straps	Across	16 to 30	18
			6 „ 16	17
			4 „ 6	16
		Along	16 to 30	22
			6 „ 16	22
			4 „ 6	18
	Rolled Bars	Double Tee and Bulb T	16 to 25	18
			6 „ 16	18
			4 „ 6	16
			3 „ 4	16
		T	16 to 25	20
			6 „ 16	20
			4 „ 6	20
			3 „ 4	18
		Angles and Bulb Plates without Flanges	16 to 25	22
			6 „ 16	22
			4 „ 6	20
			3 „ 4	18
British Admiralty Plates and Bars of all sections and thicknesses.			All Thicknesses.	20
Lloyd's Registry Plates and Bars of all sections and thicknesses			All Thicknesses.	20
Underwriters' Registry Plates and Bars of all sections and thicknesses.			All Thicknesses.	—